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Ticona

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Bishop Facility
Highway 77 South
P.O. Box 428
Bishop, TX 78343

July 8, 2011
EJM-005-11
EIJ-029-011
TPI Project – 07082011-MISC
CERTIFIED MAIL 7009 0820 0000 5077 0720

Mr. David Garcia
Associate Director
Air Toxics and Inspection Coordination Branch
U.S.EPA Region 6
1445 Ross Avenue
Dallas, TX 75202-2733

Subject: **Clean Air Act ("CAA") Section 114 Information Request – Supplemental Response**

Dear Mr. Garcia:

Ticona Polymers, Inc. (TPI) is submitting the attached supplemental response to the EPA's original CAA Section 114 Information Request dated July 2, 2010. Ticona initially responded to the Information Request on August 30, 2010. This Supplemental Response provides additional information regarding the flare events identified in your email dated January 7, 2011,

" Dear Mr. Joyner;

Attached please find a copy of the flaring data review in table form for the seven flares at your Bishop, Texas facility, as we discussed during today's call. These results are based on information you submitted in your information request response on August 30, 2010. The summary includes the results of queries performed on the flaring database provided by Ticona as well as a review of the flare operational data. Please review the findings and provide me with the results of your review by close of business Friday, January 28, 2011. As discussed on the phone call, this is an opportunity for Ticona to review the results of our data analysis to insure that it accurately depicts the compliance and operations of your facility as it relates to flaring. Please provide any necessary documentation to support your assertions.

Please call or e-mail me if you have any questions concerning the results or how we arrived at them. We are also open to meeting with you to discuss this matter.

Sincerely,

David Eppler
US EPA, Region 6, Dallas
voice: 214-665-6529
fax: 214-665-7446"

Per EPA Flare Analysis Table (Fig 1-1) there are several issue to be addressed.

I. Btu/scf events for the MO-3 & MO-4 units;

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II. Events associated with the MS unit flare;

III. Events associated with the 4 HAP unit Btu value; and

IV. GUR unit steam to full ratio.

This Supplemental Response will focus primarily on the MO-3 and MO-4 flares. TPI purchased the flares for MO-3 and MO-4 with the design specifications and operational conditions to be non-assisted flares. Documentation from the flare manufacturer, EPA published documents, and other documentation support the conclusion that both flares are operated within the correct Btu/scf range as required by 40 CFR 60.18.

In addition, this Supplemental Response includes information relating to the MS, 4 HAP and GUR units that was not included in TPI's earlier submission. With this Supplemental Response, TPI believes that it has addressed all of the questions raised regarding the EPA's Section 114 Request. Should you have any questions regarding any of the information that has been submitted or need additional information, please contact our technical representative Buddy Joyner at (361) 584-6104.

I certify under penalty of law that I have examined and am familiar with the information in the enclosed documents, including all attachments. Based on my inquiry of those individuals with primary responsibility for obtaining the information, I certify that the statements and information are, to the best of my knowledge and belief, true and complete. I am aware that there are significant penalties for knowingly submitting false statements and information, including the possibility of fines or imprisonment pursuant to Section 113(c)(2) of the Act, and 18 U.S.S. §§ 1001 and 1341.

Sincerely,

Rodolfo Morales Jr

Rudy Morales
Technical Manager for

Ed McKinley
Site Director

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Coordination Branch
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I. SUPPLEMENTAL INFORMATION REGARDING MO-3 and MO-4 FLARES

In the Flare Analysis Table (Fig 1-1), EPA identified 676 MO-3 and 83 MO-4 flare events in which the net heating value of the flare gas being combusted was less than 300 Btu per standard cubic foot ("Btu/scf"). The MO-3 and MO-4 flares are non-assisted flares. TPI purchased these flares with the design specifications and operational conditions to be non-assisted; the manufacturer has recently confirmed that the flares are non-assisted. See Attachment 7 Hoechst Celanese Callidus 5-6-11 Letter. Moreover, the flares meet with industry-wide definition of non-assist flares. Because the flares are non-assisted, they are only required to maintain 200 Btu/scf when vent gas is routed to the flare system.

EPA Flare Analysis Table
(Fig 1-1)

FLARE	Btu per Standard Cubic Foot	Steam (lbs. per lb vent gas)
MO-3	**676 Events < 300**	**Zero Events > 10**
MO-4	**83 Events < 300**	**Zero Events > 10**
MS	**31,372 Events < 200**	**N/A**
4 HAP	**33 Events < 300**	**Zero Events > 10**
GUR	**Zero Events < 300**	**60 Events > 10**
WWTP	**Zero Events < 200**	**N/A**
IBU	**Zero Events < 300**	**Zero Events >10**

Current Flare Analysis Table
(Fig 1-2)

FLARE	**Btu per Standard Cubic Foot**	**Steam (lbs. per lb vent gas)**
MO-3	**0 Events < 200**	**Zero Events > 10**
MO-4	**0 Events < 200**	**Zero Events > 10**
MS	**0 Events < 200**	**N/A**
4 HAP	**5 Events < 300**	**Zero Events > 10**
GUR	**Zero Events < 300**	**60 Events > 10**
WWTP	**Zero Events < 200**	**N/A**
IBU	**Zero Events < 300**	**Zero Events >10**

MO-3 and MO-4 Flares are Designed, Manufactured and Operated as Non-Assist Flares

Process Description

The Methanol Oxidation Units 3 &4 installed emergency flares (MO-3 and MO-4) for the purpose of reducing emissions events and to meet environmental regulations. The vendor design for the flares was to have a tip velocity less than 60 ft/s. and an LHV greater than 200 BTU/SCF. During a unit start-up, fuel gas is used to enrich the vent and raise the LHV above 200 BTU/SCF since the normal start-up vent is flammable. To insure safe operation of the flare, several safety systems are included in the design. These include a liquid seal, flashback center steam, fuel gas enrichment during start-up, and rupture discs upstream of flare divert valves. Using a flammable vapor cloud study and the location of near-by equipment, the MO3 and M04 flare heights are 190 and 140 feet, respectively. The location of the flares is adjacent to the MO3 and M04 absorbers T-314 and T-315, respectively.

To ensure that the flame does not propagate back to the process, two levels of protection exist. First, there is a liquid seal at the base of each flare. To operate the liquid seal correctly, organics must be purged from the seal during flare use. The purge rate will be approximately 20 GPM for the M04 flare and 0.5 GPM for the MO3 flare. The diameter and height of the liquid seal depend on the support stack diameter and the vapor rate. The height of the seal (liquid level above vapor entry) will be maintained between 6 and 8 inches.

In addition, during the start-up vent, the stream is enriched with fuel gas to keep it above the upper explosive limit (UEL). This is consistent with guidelines in US Coast Guard Regulation 33 CFR 154.824 (i) (3) that explain the importance of keeping the stream above the UEL to operate safely. The regulation states that the hydrocarbon concentration throughout the system should be maintained above 170 percent by volume of the UEL (4). The group contribution method was used to calculate the flammability limits of the vent gas mixture.

Center steam in the flare stack prevents flashback by keeping the tip velocity high enough to prevent backward flame propagation. When the flare is not being used, air intrusion is avoided by keeping constant nitrogen purge in the vent line and flare stack. The recommended nitrogen purge rate for the M04 flare is 500 to 1000 SCFH, and the purge rate for the MO3 flare is 150 to 450 SCFH.

The flares were designed such that, should the incinerator or vent gas system fail when the process vent is lined to the primary control device (incinerator), the vent will divert to the flare. The flare will have the pilots lit and the liquid seal on level control at all times. The incinerator to flare divert valve will simultaneously close to the incinerator and open to the flare. The vent gas line from divert valve to incinerator will automatically be purged with nitrogen.

When the unit is in the start-up mode, the process vent must go to the flare before being introduced to the incinerator. The flare will start-up on enrichment fuel gas at minimum flow. The unit may begin normal reactor start-up on nitrogen. Before switching reactor start-up nitrogen to air, the enrichment fuel gas to the flare will be placed on ratio control to the vent gas flow. When first-stage reactor air flows total at least 5000 scfm, the vent gas will be diverted from the flare to the incinerator.

MO-3 and MO-4 Flares Meet the EPA and Industry-Wide Definition for Non-Assist Flares

Although the definition of steam assist is not clearly defined in 40 CFR 60, the EPA has defined non-assist to be "a flare tip without any auxiliary provision for enhancing the mixing of air into its flame." *See* Standards of Performance for New Stationary Sources: General Provisions; National Emissions Standards for Hazardous Air Pollutants for Source Categories: General Provisions, Federal Register, May 4, 1998, page 24,440, an excerpt of which is attached as Attachment 9. In addition, there are widely accepted definitions for non-assisted flares which are consistent with the EPA's definition.

The purpose of steam assistance is to externally enhance the flame by increasing or modifying the air flow in the combustion zone. A number of published EPA and industry documents support the conclusion that steam-assisted flares use steam to control smoke. By contract, center steam at the base of the flare tip is used to prevent flashback down the flare tube and as a backup to the flare seal system. For the following three reasons, the MO-3 and MO-4 flares are non-assisted flares and subject to 200 Btu/scf:

1. **The MO-3 and MO-4 flares are not steam assisted flares.**

The MO-3 and MO-4 flares are not steam assisted flares because they do not require an external force or assist medium for smokeless flaring. *See KLM Technology Group documentation for assisted flares page 9 (*"Typical flare system consists of a provision for **external momentum force (steam injection or forced air)** for smokeless flaring." and page 11 ("To achieve smokeless operation, it is necessary to **add an assist medium to increase the overall momentum** to the smokeless burning level. **The common medium is steam which is injected into nozzles of the flare system**...")

Reference:
http://kolmetz.com/pdf/EDG/ENGINEERING%20DESIGN%20GUIDELINE-%20Flare%20Rev1.1.pdf

Also, in a typical system, steam is injected into the flare combustion zone to deliver educted air as well as mixing energy..." *See Clean Air Engineering Inc., Detroit Performance Test of Steam-Assisted Elevated Flare Marathon Petroleum Company, Detroit CP Flare Final Report November 23, 2010 Final Report, page 11.*

Reference: http:// epa.gov/airtoxics/techres.html

See Attachment 8 for additional Manufacturer information to support that MO-3 and MO-4 are not steam-assisted flares.

2. The MO-3 and MO-4 flares are non-assisted flares.

The MO-3 and MO-4 flares non-assisted flares because no mixing is taking place "AT THE TIP". The center steam, enrichment gas and waste gas all establish the core gas that will be ignited above the burner tip. These flares do not have "any auxiliary provision for enhancing the mixing of air into its flame…" or "steam [that] is injected into the combustion zone to promote turbulence for the mixing of the combustion air before it is introduced to the flame." *See* San Joaquin Valley Air Rule 4311 Flares (adopted June 20, 2002; amended June 19, 2006; amended June 18, 2009) pages 2 & 4.

Reference: http://valleyair.org/rules/currntrules/r4311.pdf
EPA/452/B-02-001document Section 3 VOC Control Chapter 1 Flares dated September 2000 (Attachment 3) page 1-4

3. The center steam does not provide auxiliary mixing of air into its flame.

Flares are generally categorized in two ways: (1) by the height of the flare tip (i.e., ground or elevated), and (2) by the method of enhancing mixing at the flare tip (i.e., steam-assisted, air assisted, pressure-assisted, or non-assisted).

In most flares, combustion occurs by means of a diffusion flame. A diffusion flame is one in which air diffuses across the boundary of the fuel/combustion product stream toward the center of the fuel flow, forming the envelope of a combustible gas mixture around a core of fuel gas. This mixture, on ignition, establishes a stable flame zone around the gas core above the burner tip. This inner gas core is heated by diffusion of hot combustion products from the flame zone."

Reference: EPA/452/B-02-001 document, Section 3 VOC Control Chapter 1 Flares page 1-3, introduction 1.1.1

As the EPA has recognized, the flaring process can produce some undesirable consequence. One such consequence is flashback or the flame traveling down the flare tube. These unintended consequences can be minimized by proper flare design. Callidus, the manufacturer of the MO-3 and MO-4 flares, designs flares with center steam to avoid flashback.

Reference:
EPA/452/B-02-001document Section 3 VOC Control Chapter 1 Flares dated September 2000 (Attachment 3) states on page 1-3 under introduction 1.1 second paragraph.

http://www.epa.gov/ttn/catc/dir1/cs3-
www.epa.gov/ttn/catc/dir1/fflare.wpd (copy to browser)**
http://nepis.epa.gov/exe/zynet.exe/200mf11.txt ***

Callidus's Proposal for the MO-3 and MO-4 flares identifies three levels of defense against flashback from gas/oxygen in the header system. See Callidus Proposal, attached as Attachment1, at Section BI.[1] In its proposal, Callidus explains that, "It is necessary to ensure that the velocity for the flare tip is always maintained at significantly greater than the flame speed back in order to prevent flashback at the tip. This is most easily accomplished by injecting a steam purge near the top of the flare tip through a special center injector. Our standard design utilizes medium pressure steam and natural gas as the second level of defense to accomplish this velocity."
Callidus also recommends not putting a molecular or density type seal. But as the steam and/or natural gas added below the flare tip increase the velocity of the fuel stream it would be treated as part of the process.

During a recent unit outage TPI was able to obtain a photograph of the MO-4 flare from the flare tip looking down into the flare tube. The photograph labeled as "Center Steam Line Attachment 2" shows that the center steam is below the base of the flare tip and is actually in the flare tube. The design of the center steam injector would work similar to an umbrella causing the steam to be diverted down into or across the fuel at a low or medium volume. The design and purpose of this steam injection system was never intended to inspirate the waste gas stream or to prevent smoking as is the purpose of injecting steam at the tip of a flare.

Callidus reinforced this in Section C.I.4 of its proposal: "The steam system provides one of the levels of defense for flashback protection from the gas in the header system. It is imperative that the velocity at the flare tip is always maintained significantly greater than the flame speed in order to prevent flashback at the tip."

In a recent email to Celanese, Callidus again makes clear that, "Even though the center steam is close to the exit of the tip, there is no air inside the flare tip so it is not possible for the center steam to inspirate air into the flame." See Attachment 4 Callidus email from Brian Duck

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[1] The EPA has recognized that flare manufacturers of proprietary flare systems are uniquely situated to are in the best position to determine the minimum necessary steam rate. *See* EPA/452/B-02-001document, Section 3 VOC Control, Chapter 1 Flares, dated September 2000 (Attachment 3) page 1-21 under Steam Requirements ("...if a proprietary smokeless flare is purchased, the manufacturer should be consulted about the minimum necessary steam rate.")

Moreover, API Standard 537, section 5.1.3, Attachment 5, supports the conclusion that center steam is used to support the flare tip and not to assist combustion. "While steam assist enhances the combustion of relief gases that will smoke, it will adversely affect the combustion of relief gases with high levels of inerts."

The normal vent stream to the MO-3 flare was sampled on 5/10/2011 and analyzed in the TPI on-site laboratory. The analysis of this sampling can be found in MO-3 Vent Analysis Attachment 6. This analysis demonstrates that there is a high inert composition in this vent stream and would not be a suitable stream for using a steam assisted flare.

Conclusion

Based on the flare manufacturer's proposal documentation and subsequent supporting email, EPA published guidance and relevant industry documentation, the MO-3 and MO-4 flares are non-assisted. As such, these flares must be operated above 200 Btu/scf, not above 300 Btu/scf. The spreadsheet information submitted on the Attached compact disc documents both flares were above 200 Btu/scf at all times when vent gas was directed to the flare.

II. SUPPLEMENTAL INFORMATION REGARDING MS FLARE EVENTS

The MS unit flare provides emission control for 3 methanol storage tanks, and is an emergency vent for a waste gas stream that is normally burned in the utilities boiler. The vent stream from the 3 storage tanks is minimal and will not sustain the 200 Btu/scf heating value required at the flare. Natural gas, or enrichment gas, is added through FV-315 flow valve to the storage tank vent stream in order to meet or exceed the required Btu value.

Per the attached calculation spreadsheet (Attachment MS-2 on compact disc) Column "O" shows enrichment gas addition to the flare via FV-315. Prior to 2007 this flow was operated by a field mounted hand controller HIC-315. In order to maintain better control a flow transmitter was added which can send data to our PI historian.

Data prior to January 3, 2007 is not available, but TPI reviewed all data from 2007. The lowest enrichment gas value for 2007 was 112.4 Btu/scf. This was recorded on March 13, 2007 10:00 (column 7606 on the spreadsheet). Taking this value as a conservative estimate for the enrichment gas for the period of May 1, 2006 through January 3, 2007 08:00 the total Btu/scf never falls below the required 200 Btu/scf.

Attachment MS-1 Process Description with Photos
Attachment MS-2 MS Flare Data Rev3

III. SUPPLEMENTAL INFORMATION REGARDING 4 HAP FLARE BTU EVENTS

EPA identified 33 events when the 4 HAP Flare was <300 Btu. TPI has determined that these events all coincide with tank filling events and are of short duration. Only five of the 33 events (6/18/07; 9/19/07; 9/19/07; 9/20/07; 9/21/07) resulted in gas venting to the flare.

These five events resulted from an indication of pressure change in the HF storage tank, V-2816.

Twenty-seven events (11/3/07; 11/10/07; 11/13/07; 11/22/07; 11/24/07; 11/25/07; 11/26/07; 11/28/07; 12/02/07; 12/10/07; 12/13/07; 12/15/07; 12/19/07; 12/20/07; 12/22/07; 1/5/08; 10/17/08; 10/20/08; 10/23/08; 10/26/08; 10/27/08; 10/29/08; 10/30/08; 11/3/08; 11/5/08; 11/9/08; 11/11/08) resulted from an indication of level increase in V-2719, a vessel which was being used for pentanol storage at the time. An increase in level was assumed to result in the venting of the vapor space from the vessel. However, during each of these 27 events, the level increase was the result of a transfer of pentanol from a trailer to the vessel while the vessel was vapor balanced to the trailer. These vapor-balancing activities did not result in any venting to the flare.

The event on 6/28/07 was the result of performing a pressure test on the vessel pressure transmitter. This test was performed on a short section of pipe and not the whole vessel. The calibration of the pressure transmitter resulted in a false indication of flow; however, TPI has confirmed that there was venting to the flare during this event.

As a result, no venting to the header occurred during these 28 events associated with the 4-HAP Flare. A calculation spreadsheet is being submitted on disc with revised calculations. 4 HAP Flare 2006-2010 Rev2

IV. SUPPLEMENTAL INFORMATION REGARDING GUR FLARE EVENTS

60 steam to vent gas ratios >10 events from the GUR Flare have been retrieved and found to be random. TPI is continuing to investigate ways to reduce steam usage while still operating the flares safely and efficiently.

Steam to vent gas ratios increased for 3 hours on 9/7/06 due to a hexane storage tank being steamed out for maintenance prior to this steam addition. It is believed that the increased steam to the flare was due to flare smoking. At this point the hexane boiling had stopped, but steam addition remained.

Steam to vent gas ratio increased for 2 hours on 10/22/06 due to the flare being shutdown at 5:30 a.m. The vent streams were being isolated to prepare for the flare outage.

During turnaround situations each year there were 54 hours when the steam to vent gas ratio increased. At the time of the increased steam, the venting rate is very low as several vessels are empty.

On 7/20/10 during a turnaround, there was 1 hour when the steam to vent gas increased. This occurred just after re-commissioning the flare and some of the extra nitrogen purges to the flare were reduced leading to a lower indicated venting rate.

Attachments:

1) Callidus Proposal
2) Center Steam Line Picture
3) Chapter 3 EPA Document
4) Callidus Email from Brian Duck
5) API Standard 537
6) MO-3 Vent Analysis
7) Hoechst Celanese 5-6-11 Callidus Letter
8) Additional Mfg's Definition of Assisted Flare
9) Excerpt from Federal Register, May 4, 1998, page 24,440

Attachment MS-1	Process Description with Photos
Attachment MS-2	MS Flare Data Rev3 (on compact disc)
Attachment MO-3	MO-3 Flare Data (on compact disc)
Attachment MO-4	MO-4 Flare Data (on compact disc)

ATTACHMENT 1

Callidus Proposal

CALLIDUS TECHNOLOGIES INC.
The Environmental & Combustion Experts.

September 8, 1995

Hoechst Celanese Corp.
P.O. Box 428
Bishop, TX 78343

RE: M03 and M04 Flare Systems
Callidus File No. F-9411-1767-HT-Rev. 2

Attention: Mr. Greg Page

Gentlemen:

The **Callidus** team has been involved in the design of integrated flare systems since mid-1974. Members of the **Callidus** team have been responsible for the design and start-up of hundreds of flare systems. Of particular importance to this project is the team's experience with integrated flare systems. Since the 1970's, the **Callidus** team has been intimately involved in the development, design, and start-up of hundreds of elevated flare systems. This experience includes the selection and design of the burner system and ancillary control equipment as well as the structural design of the stack support equipment and ancillaries. The application which you have presented represents a flare for which the unique experience and talents of the **Callidus** team are well matched.

An important consideration in the design of the flare system is the ability to accurately predict thermal radiation from flare releases. The **Callidus** team was involved for over 15 years in the collection and reduction of flare radiation data and in the development of models to allow prediction of radiation. In this effort, members of this team spent a significant amount of time in the Middle East, in Kuwait and Saudi Arabia, collecting data from large releases of flare systems. In addition, they were afforded the opportunity to be involved in test work under controlled conditions in a research and development facility where data from controlled flare tests of medium size releases was collected and reduced. The **Callidus** personnel feel very confident in their ability to accurately predict thermal radiation from large-scale flare releases.

Callidus' structural engineers possess over 20 years of experience in the design of flare systems, including derrick, self-supporting, and guyed structures. This experience and talent will result in a cost effective, structurally sound system designed to provide support for a flare system. The design will include considerations for those unique features of temperature differential and other factors which occur in a flare system but do not occur in a normal vent stack.

Callidus sincerely appreciates the opportunity to present this proposal, and we appreciate the time and effort you will take in reviewing and evaluating our offering.

Let me assure you of our pledge to a technically competent, timely completion of any work which **Hoechst Celanese Corp.** commits to **Callidus**. With these comments in mind, we are pleased to offer our attached proposal.

Best regards,

Brian Duck, P.E.
Product Line Manager

cc: Mr. David Giles, Enviropro

/fc

ATTACHMENT 2

Center Steam Line Picture

ATTACHMENT 3

Chapter 3 EPA Document

EPA/452/B-02-001

Section 3

VOC Controls

EPA/452/B-02-001

Section 3.2

VOC Destruction Controls

EPA/452/B-02-001

Chapter 1

Flares

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September 2000

Contents

1.1 Introduction

Flaring is a volatile combustion control process for organic compound (VOC) in which the VOCs are piped to a remote, usually elevated, location and burned in an open flame in the open air using a specially designed burner tip, auxiliary fuel, and steam or air to promote mixing for nearly complete (> 98%) VOC destruction. Completeness of combustion in a flare is governed by flame temperature, residence time in the combustion zone, turbulent mixing of the components to complete the oxidation reaction, and available oxygen for free radical formation. Combustion is complete if all VOCs are converted to carbon dioxide and water. Incomplete combustion results in some of the VOC being unaltered or converted to other organic compounds such as aldehydes or acids.

The flaring process can produce some undesirable by-products including noise, smoke, heat radiation, light, sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and an additional source of ignition where not desired. However, by proper design these can be minimized.

1.1.1 Flare Types

Flares are generally categorized in two ways: (1) by the height of the flare tip (i.e., ground or elevated), and (2) by the method of enhancing mixing at the flare tip (i.e., steam-assisted, air-assisted, pressure-assisted, or non-assisted). Elevating the flare can prevent potentially dangerous conditions at ground level where the open flame (i.e., an ignition source) is located near a process unit. Further, the products of combustion can be dispersed above working areas to reduce the effects of noise, heat, smoke, and objectionable odors.

In most flares, combustion occurs by means of a diffusion flame. A diffusion flame is one in which air diffuses across the boundary of the fuel/combustion product stream toward the center of the fuel flow, forming the envelope of a combustible gas mixture around a core of fuel gas. This mixture, on ignition, establishes a stable flame zone around the gas core above the burner tip. This inner gas core is heated by diffusion of hot combustion products from the flame zone.

Cracking can occur with the formation of small hot particles of carbon that give the flame its characteristic luminosity. If there is an oxygen deficiency and if the carbon particles are cooled to below their ignition temperature, smoking occurs. In large diffusion flames, combustion product vortices can form around burning portions of the gas and shut off the supply of oxygen. This localized instability causes flame flickering, which can be accompanied by soot formation.

As in all combustion processes, an adequate air supply and good mixing are required to complete combustion and minimize smoke. The various flare designs differ primarily in their accomplishment of mixing.

Steam-Assisted Flares

Steam-assisted flares are single burner tips, elevated above ground level for safety reasons, that burn the vented gas in essentially a diffusion flame. They reportedly account for the majority of the flares installed and are the predominant flare type found in refineries and chemical plants.[1,2]

To ensure an adequate air supply and good mixing, this type of flare system injects steam into the combustion zone to promote turbulence for mixing and to induce air into the flame. Steam-assisted flares are the focus of the chapter and will be discussed in greater detail in Sections 1.2 through 1.4.

Air-Assisted Flares

Some flares use forced air to provide the combustion air and the mixing required for smokeless operation. These flares are built with a spider-shaped burner (with many small gas orifices) located inside but near the top of a steel cylinder two feet or more in diameter. Combustion air is provided by a fan in the bottom of the cylinder. The amount of combustion air can be varied by varying the fan speed. The principal advantage of the air-assisted flares is that they can be used where steam is not available. Although air assist is not usually used on large flares (because it is generally not economical when the gas volume is large[3]) the number of large air-assisted flares being built is increasing.[4]

Non-Assisted Flares

The non-assisted flare is just a flare tip without any auxiliary provision for enhancing the mixing of air into its flame. Its use is limited essentially to gas streams that have a low heat content and a low carbon/hydrogen ratio that burn readily without producing smoke.[5] These streams require less air for complete combustion, have lower combustion temperatures that minimize cracking reactions, and are more resistant to cracking.

Pressure-Assisted Flares

Pressure-assisted flares use the vent stream pressure to promote mixing at the burner tip. Several vendors now market proprietary, high pressure drop burner tip designs. If sufficient vent stream pressure is available, these flares can be applied to streams previously requiring steam or air assist for smokeless operation. Pressure-assisted flares generally (but not necessarily) have the burner arrangement at ground level, and consequently, must be located in a remote area of the plant where there is plenty of space available. They have multiple burner heads that are staged to operate based on the quantity of gas being released. The size, design, number, and group arrangement of the burner heads depend on the vent gas characteristics.

Enclosed Ground Flares

An enclosed flare's burner heads are inside a shell that is internally insulated. This shell reduces noise, luminosity, and heat radiation and provides wind protection. A high nozzle pressure drop is usually adequate to provide the mixing necessary for smokeless operation and air or steam assist is not required. In this context, enclosed flares can be considered a special class of pressure-assisted or non-assisted flares. The height must be adequate for creating enough draft to supply sufficient air for smokeless combustion and for dispersion of the thermal plume. These flares are always at ground level.

Enclosed flares generally have less capacity than open flares and are used to combust continuous, constant flow vent streams, although reliable and efficient operation can be attained over a wide range of design capacity. Stable combustion can be obtained with lower Btu content vent gases than is possible with open flare designs (50 to 60 Btu/scf has been reported)[2], probably due to their isolation from wind effects. Enclosed flares are typically found at landfills.

1.1.2 Applicability

Flares can be used to control almost any VOC stream, and can handle fluctuations in VOC concentration, flow rate, heating value, and inerts content. Flaring is appropriate for continuous, batch, and variable flow vent stream applications. The majority of chemical plants and refineries have existing flare systems designed to relieve emergency process upsets that require release of large volumes of gas. These large diameter flares designed to handle emergency releases, can also be used to control vent streams from various process operations. Consideration of vent stream flow rate and available pressure must be given for retrofit applications. Normally, emergency relief flare systems are operated at a small percentage of capacity and at negligible pressure. To consider the effect of controlling an additional vent stream, the maximum gas velocity, system pressure, and ground level heat radiation during an emergency release must be evaluated. Further, if the vent stream pressure is not sufficient to overcome the flare system pressure, then the economics of a gas mover system must be evaluated, If adding the vent stream causes the maximum velocity limits or ground level heat radiation limits to be exceeded, then a retrofit application is not viable.

Many flare systems are currently operated in conjunction with baseload gas recovery systems. These systems recover and compress the waste VOC for use as a feedstock in other processes or as fuel. When baseload gas recovery systems are applied, the flare is used in a backup capacity and for emergency releases. Depending on the quantity of usable VOC that can be recovered, there can be a considerable economic advantage over operation of a flare alone.

Streams containing high concentrations of halogenated or sulfur containing compounds are not usually flared due to corrosion of the flare tip or formation of secondary pollutants (such as SO_2). If these vent types are to be controlled by combustion, thermal incineration, followed by scrubbing to remove the acid gases, is the preferred method.[3]

1.1.3 Performance

This section discusses the parameters that affect flare VOC destruction efficiency and presents the specifications that must be followed when flares are used to comply with EPA air emission standards.

1.1.3.1 Factors Affecting Efficiency

The major factors affecting flare combustion efficiency are vent gas flammability, auto-ignition temperature, heating value (Btu/scf), density, and flame zone mixing.

The flammability limits of the flared gases influence ignition stability and flame extinction. The flammability limits are defined as the stoichiometric composition limits (maximum and minimum) of an oxygen-fuel mixture that will burn indefinitely at given conditions of temperature and pressure without further ignition. In other words, gases must be within their flammability limits to burn. When flammability limits are narrow, the interior of the flame may have insufficient air for the mixture to burn. Fuels, such as hydrogen, with wide limits of flammability are therefore easier to combust.

For most vent streams, the heating value also affects flame stability, emissions, and flame structure. A lower heating value produces a cooler flame that does not favor combustion kinetics and is also more easily extinguished. The lower flame temperature also reduces buoyant forces, which reduces mixing.

The density of the vent stream also affects the structure and stability of the flame through the effect on buoyancy and mixing. By design, the velocity in many flares is very low; therefore, most of the flame structure is developed through buoyant forces as a result of combustion. Lighter gases therefore tend to burn better. In addition to burner tip design, the density also directly affects the minimum purge gas required to prevent flashback, with lighter gases requiring more purge.[5]

Poor mixing at the flare tip is the primary cause of flare smoking when burning a given material. Streams with high carbon-to-hydrogen mole ratio (greater than 0.35) have a greater tendency to smoke and require better mixing for smokeless flaring.[3] For this reason one generic steam-to-vent gas ratio is not necessarily appropriate for all vent streams. The required steam rate is dependent on the carbon to hydrogen ratio of the gas being flared. A high ratio requires more steam to prevent a smoking flare.

1.1.3.2 Flare Specifications

At too high an exit velocity, the flame can lift off the tip and flame out, while at too low a velocity, it can burn back into the tip or down the sides of the stack.

The EPA requirements for flares used to comply with EPA air emission standards are specified in 40 CFR Section 60.18. The requirements are for steam-assisted, air-assisted, and non-assisted flares. Requirements for steam-assisted, elevated flares state that the flare shall be designed for and operated with:

- an exit velocity at the flare tip of less than 60 ft/sec for 300 Btu/scf gas streams and less than 400 ft/sec for >1,000 Btu/scf gas streams. For gas streams between 300-1,000 Btu/scf the maximum permitted velocity (V_{max}, in ft/sec) is determined by the following equation:

$$\log_{10}(V_{max}) = \frac{B_v + 1{,}214}{852} \tag{7.1}$$

- where B_v is the net heating value in Btu/scf.

- no visible emissions. A five-minute exception period is allowed during any two consecutive hours.

- a flame present at all times when emissions may be vented. The presence of a pilot flame shall be monitored using a thermocouple or equivalent device.

- the net heating value of the gas being combusted being 300 Btu/scf or greater.

In addition, owners or operators must monitor to ensure that flares are operated and maintained in conformance with their design.

1.2 Process Description

The elements of an elevated steam-assisted flare generally consist of gas vent collection piping, utilities (fuel, steam, and air), piping from the base up, knock-out drum, liquid seal, flare stack, gas seal, burner tip, pilot burners, steam jets, ignition system, and controls. Figure 7.1 is a diagram of a steam-assisted elevated smokeless flare system showing the usual components that are included.

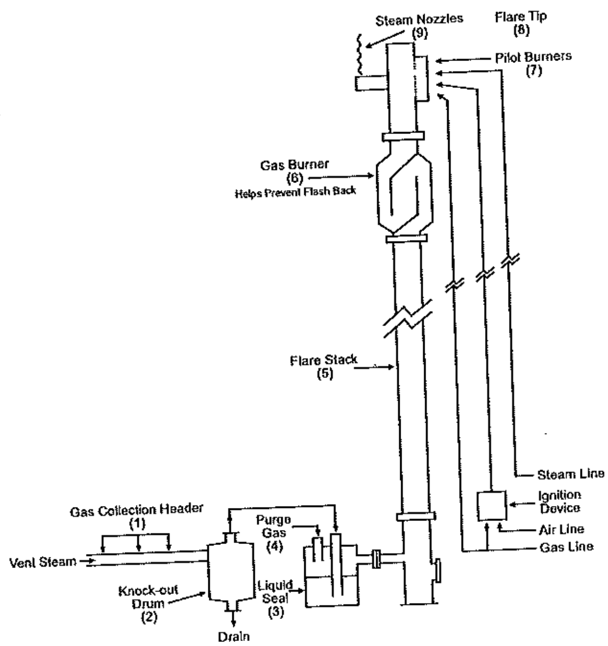

Figure 1.1: Steam-Assisted Elevated Flare System

1.2.1 Gas Transport Piping

Process vent streams are sent from the facility release point to the flare location through the gas collection header. The piping (generally schedule 40 carbon steel) is designed to minimize pressure drop. Ducting is not used as it is more prone to air leaks. Valving should be kept to an absolute minimum and should be "car-sealed" (sealed) open. Pipe layout is designed to avoid any potential dead legs and liquid traps. The piping is equipped for purging so that explosive mixtures do not occur in the flare system either on start-up or during operation.

1.2.2 Knock-out Drum

Liquids that may be in the vent stream gas or that may condense out in the collection header and transfer lines are removed by a knock-out drum. (See Figure 1.2.) The knock-out or disentrainment drum is typically either a horizontal or vertical vessel located at or close to the base of the flare, or a vertical vessel located inside the base of the flare stack. Liquid in the vent stream can extinguish the flame or cause iregular combustion and smoking. \in addition, flaring liquids can generate a spray of burning chemicals that could reach group level and create a safety hazard. For a flare system designed to handle emergency process upsets this drum must be sized for worst-case conditions (e.g., loss of cooling water or total unit depressuring) and is usually quite large. For a flare system devoted only to vent stream VOC control, the sizing of the drum is based primarily on vent gas fow rate with consideration given to liquid entrainment.

1.2.3 Liquid Seal

Process vent streams are usually passed through a liquid seal before going to the flare stack. The liquid seal can be downstream of the knockout drum or incorporated into the same vessel. This prevents possible flame flashbacks, caused when air is inadvertently introduced into the flare system and the flame front pulls down into the stack. The liquid seal also serves to maintain a positive pressure on the upstream system and acts as a mechanical damper on any explosive shock wave in the flare stack. Other devices, such as flame arresters and check valves, may sometimes replace a liquid seal or be used in conjunction wit hit. Purge gas (as discussed in Section 1.3.4) also helps to prevent flashback in the flare stack cause by low vent gas flow.

1.2.4 Flare Stack

For safety reasons a stack is used to elevate the flare. The flare must be located so that it does not present a hazard to surrounding personnel and facilities. Elevated flares can be self-supported (free-standing), guyed, or structurally supported by a derrick. Examples of these three types of elevated flares are shown in Figures 1.3, 1.4, and 1.5 for self-supported, derrick supported, and guy-supported flares, respectively. Self-supporting flares are generally used for lower flare tower heights (30-100 feet) but can be designed for up to 250 feet. Guy towers are designed for over 300 feet, while derrick towers are designed for above 200 feet.[4, 6, 7, 8, 9, 10]

Free-standing flares provide ideal structural support. However, for very high units the costs increase rapidly. In addition, the foundation required and nature of the soil must be considered.

Derrick-supported flares can be built as high as required since the system load is spread over the derrick structure. This design provides for differential expansion between the stack, piping, and derrick. Derrick-supported flares are the most expensive design for a given flare height.

The guy-supported flare is the simplest of all the support methods. However, a considerable amount of land is required since the guy wires are widely spread apart. A rule of thumb for space required to erect a guy-supported flare is a circle on the ground with a radius equal to the height of the flare stack.[6]

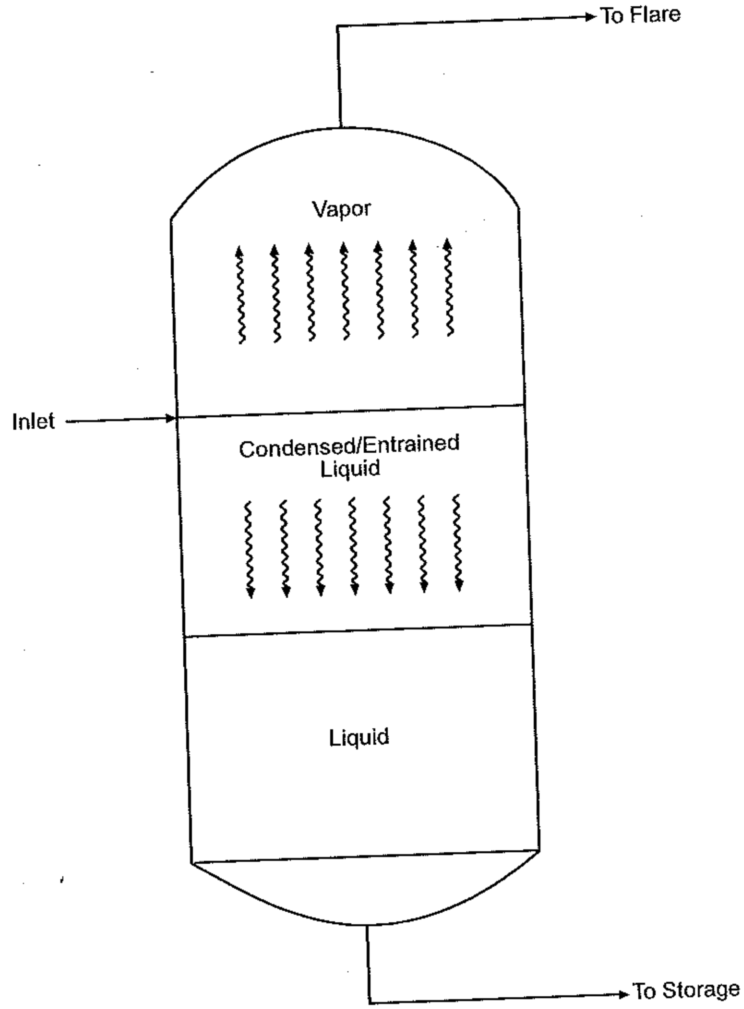

Figure 1.2: Typical Vertical Knock-out Drum

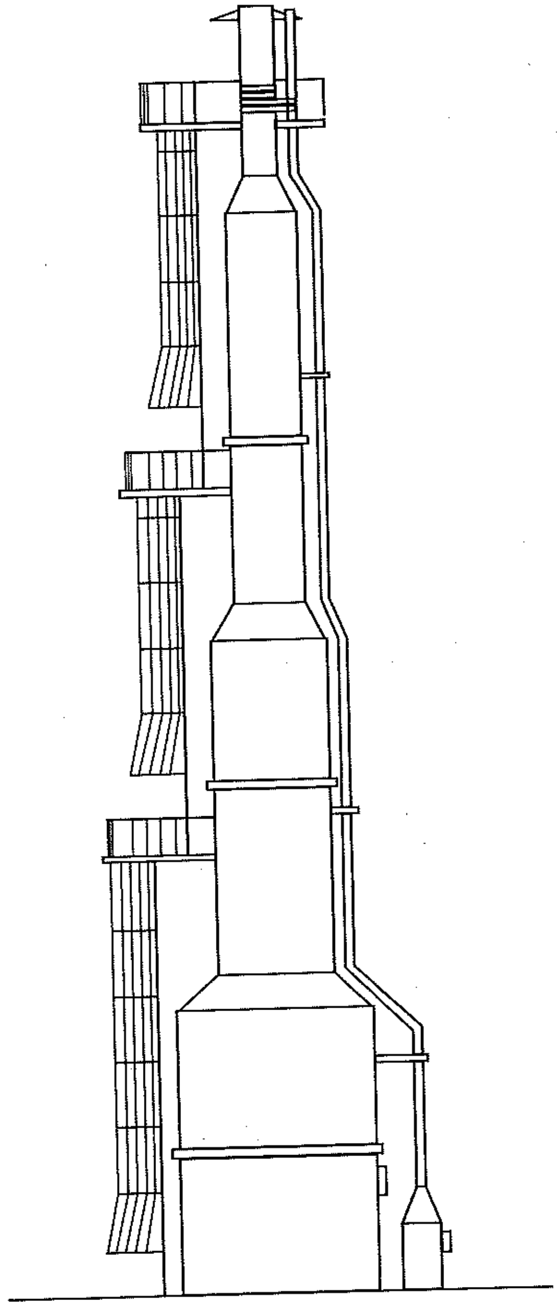

Figure 1.3: Self-Supported Elevated Flare

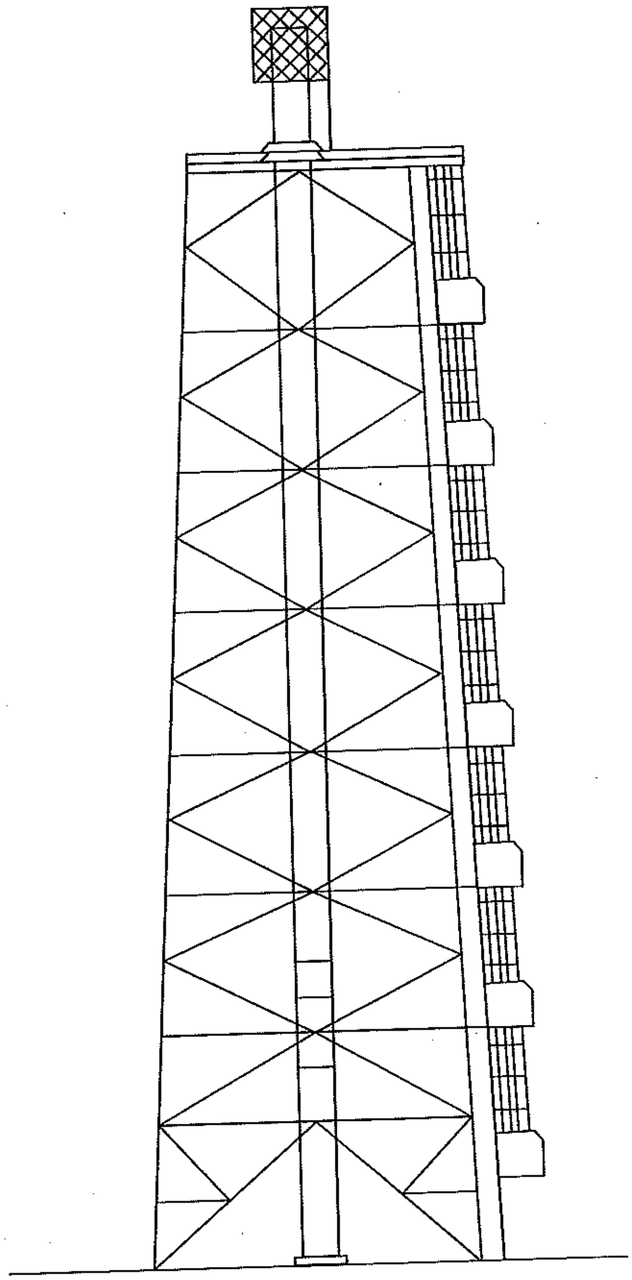

Figure 1.4: Derrick-Supported Elevated Flare

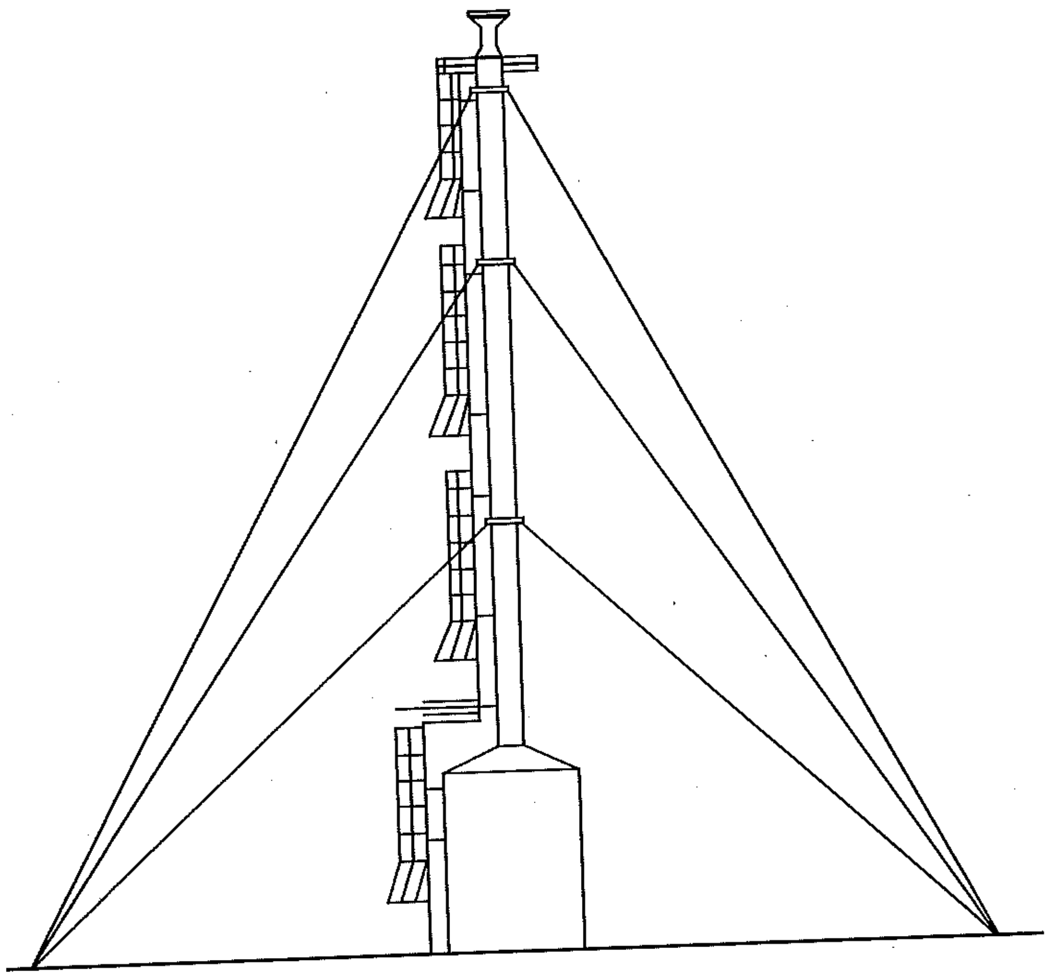

Figure 1.5: Guy-Supported Elevated Flare

1.2.5 Gas Seal

Air may tend to flow back into a flare stack due to wind or the thermal contraction of stack gases and create an explosion potential. To prevent this, a gas seal is typically installed in the flare stack. One type of gas seal (also referred to as a flare seal, stack seal, labyrinth seal, or gas barrier) is located below the flare tip to impede the flow of air back into the flare gas network. There are also "seals" which act as orifices in the top of the stack to reduce the purge gas volume for a given velocity and also interfere with the passage of air down the stack from the upper rim. These are known by the names "internal gas seal, fluidic-seal, and arrestor seal".[5] These seals are usually proprietary in design, and their presence reduces the operating purge gas requirements.

1.2.6 Burner Tip

The burner tip, or flare tip, is designed to give environmentally acceptable combustion of the vent gas over the flare system's capacity range. The burner tips are normally proprietary in design. Consideration is given to flame stability, ignition reliability, and noise suppression. The maximum and minimum capacity of a flare to burn a flared gas with a stable flame (not necessarily smokeless) is a function of tip design. Flame stability can be enhanced by flame holder retention devices incorporated in the flare tip inner circumference. Burner tips with modern flame holder designs can have a stable flame over a flare gas exit velocity range of 1 to 600 ft/sec.[2] The actual maximum capacity of a flare tip is usually limited by the vent stream pressure available to overcome the system pressure drop. Elevated flares diameters are normally sized to provide vapor velocities at maximum throughput of about 50 percent of the sonic velocity of the gas subject to the constraints of CFR 60.18.[1]

1.2.7 Pilot Burners

EPA regulations require the presence of a continuous flame. Reliable ignition is obtained by continuous pilot burners designed for stability and positioned around the outer perimeter of the flare tip. The pilot burners are ignited by an ignition source system, which can be designed for either manual or automatic actuation. Automatic systems are generally activated by a flame detection device using either a thermocouple, an infra-red sensor or, more rarely, (for ground flare applications) an ultra-violet sensor.[4]

1.2.8 Steam Jets

A diffusion flame receives its combustion oxygen by diffusion of air into the flame from the surrounding atmosphere. The high volume of fuel flow in a flare may require more combustion air at a faster rate than simple gas diffusion can supply. High velocity steam injection nozzles, positioned around the outer perimeter of the flare tip, increase gas turbulence in the flame boundary zones, drawing in more combustion air and improving combustion efficiency. For the larger flares, steam can also be injected concentrically into the flare tip.

The injection of steam into a flare flame can produce other results in addition to air entrainment and turbulence. Three mechanisms in which steam reduces smoke formation have been presented.[1] Briefly, one theory suggests that steam separates the hydrocarbon molecule, thereby minimizing polymerization, and forms oxygen compounds that burn at a reduced rate and temperature not conducive to cracking and polymerization. Another theory claims that water vapor reacts with the carbon particles to form CO, CO_2, and H_2, thereby removing the carbon before it cools and forms smoke. An additional effect of the steam is to reduce the temperature in the core of the flame and suppress thermal cracking.[5] The physical limitation on the quantity of steam that can be delivered and injected into the flare flame determines the smokeless capacity of the flare. Smokeless capacity refers to the volume of gas that can be combusted in a flare without smoke generation. The smokeless capacity is usually less than the stable flame capacity of the burner tip.

Significant disadvantages of steam usage are the increased noise and cost. Steam aggravates the flare noise problem by producing high-frequency jet noise. The jet noise can be reduced by the use of small multiple steam jets and, if necessary, by acoustical shrouding. Steam injection is usually controlled manually with the operator observing the flare (either directly or on a television monitor) and adding steam as required to maintain smokeless operation. To optimize steam usage infrared sensors are available that sense flare flame characteristics and adjust the steam flow rate automatically to maintain smokeless operation. Automatic control, based on flare gas flow and flame radiation, gives a faster response to the need for steam and a better adjustment of the quantity required. If a manual system is used, steam metering should be installed to significantly increase operator awareness and reduce steam consumption.

1.2.9 Controls

Flare system control can be completely automated or completely manual. Components of a flare system which can be controlled automatically include the auxiliary gas, steam injection, and the ignition system. Fuel gas consumption can be minimized by continuously measuring the vent gas low rate and heat content (Btu/scf) and automatically adjusting the amount of auxiliary fuel to maintain the required minimum of 300 Btu/scf for steam-assisted flares. Steam consumption can likewise be minimized by controlling flow based on vent gas flow rate. Steam flow can also be controlled using visual smoke monitors. Automatic ignition panels sense the presence of a flame with either visual or thermal sensors and reignite the pilots when flameouts occur.

1.3 Design Procedures

Flare design is influenced by several factors, including the availability of space, the characteristics of the flare gas (namely composition, quantity, and pressure level) and occupational concerns. The sizing of flares requires determination of the required flare tip diameter and height. The emphasis of this section will be to size a steam-assisted elevated flare for a given application.

1.3.1 Auxiliary Fuel Requirement

The flare tip diameter is a function of the vent gas flow rate plus the auxiliary fuel and purge gas flow rate. The purge gas flow rate is very small relative to the vent gas and fuel flow rates, so it may be ignored when determining the tip diameter. The flow rate of the auxiliary fuel, if required, is significant, and must be calculated before the tip diameter can be computed.

Some flares are provided with auxiliary fuel to combust hydrocarbon vapors when a lean flare gas stream falls below the flammability range or heating value necessary to sustain a stable flame. The amount of fuel required, F, is calculated based on maintaining the vent gas stream net heating value at the minimum of 300 Btu/scf required by rules defined in the Federal Register (see next section):

$$Q\,B_v + F\,B_f = (Q + F)\left(300\ \frac{Btu}{scf}\right) \tag{1.2}$$

where

Q = the vent stream flow rate, scfm

B_v and B_f are the Btu/scf of the vent stream and fuel, respectively.

Rearranging gives:

$$F\ (scfm) = Q\left(\frac{300 - B_v}{B_f - 300}\right) \tag{1.3}$$

The annual auxiliary fuel requirement, F_a, is calculated by:

$$F_a\left(\frac{\text{Mscf}}{\text{yr}}\right) \doteq F(\text{scfm})\ 60\left(\frac{\text{min}}{\text{hr}}\right)8760\left(\frac{\text{hr}}{\text{yr}}\right) = 526\ F\ \frac{\text{scfm}}{\text{yr}} \tag{1.4}$$

Typical natural gas has a net heating value of about 1,000 Btu/scf. Automatic control of the auxiliary fuel is ideal for processes with large fluctuations in VOC compositions. These flares are used for the disposal of such streams as sulfur tail gases and ammonia waste gases, as well as any low Btu vent streams.[2]

1.3.2 Flare Tip Diameter

Flare tip diameter is generally sized on a velocity basis, although pressure drop must also be checked. Flare tip sizing for flares used to comply with EPA air emission standards is governed by rules defined in the Federal Register (see 40 CFR 60.18). To comply with these requirements, the maximum velocity of a steam-assisted elevated flare is given in Table 1.1:

Table 1.1: Maximum Velocity of Steam-Assisted Elevated Flare

Net Heating Value of Vent Stream B_v *(Btu/scf)*	**Maximum Velocity V_{max} *(ft/sec)***
300 300 - 1,000 > 1,000	$log_{10}(V_{max}) = \frac{(B_v + 1{,}214)}{852}$

By determining the maximum allowed velocity, V_{max} (ft/sec), and knowing the total volumetric flow rate, Q_{tot} (acfm), including vent stream and auxiliary fuel gas, a minimum flare tip diameter, D_{min} (in), can be calculated. It is standard practice to size the flare so that the design velocity of flow rate Q_{tot}, is 80 percent of V_{max}, i.e.:

$$D_{min}\ (in) = 12 \sqrt{\frac{\frac{4}{\pi}\ \frac{Q_{tot}}{60\left(\frac{sec}{min}\right)}}{0.8\ V_{max}}} = 1.95 \sqrt{\frac{Q_{tot}}{V_{max}}} \tag{1.5}$$

where

Q_{tot} = $Q + F$ (measured at stream temperature and pressure)

The flare tip diameter, D, is the calculated diameter, $D = D_{min}$, rounded up to the next commercially available size. The minimum flare size is 1 inch; larger sizes are available in 2-inch increments from 2 to 24 inches and in 6-inch increments above 24 inches. The maximum size commercially available is 90 inches.[5]

A pressure drop calculation is required at this point to ensure that the vent stream has sufficient pressure to overcome the pressure drop occurring through the flare system at maximum flow conditions. The pressure drop calculation is site specific but must take into account losses through the collection header and piping, the knock-out drum, the liquid seal, the flare stack, the gas seal, and finally the flare tip. Piping size should be assumed equal to the flare tip diameter. Schedule 40 carbon steel pipe is typically used. If sufficient pressure is not available, the economics of either a larger flare system (pressure drop is inversely proportional to the pipe diameter) or a mover such as a fan or compressor must be weighed. (Refer to Section 1.3.8 for typical pressure drop relationships.)

1.3.3 Flare Height

The height of a flare is determined based on the ground level limitations of thermal radiation intensity, luminosity, noise, height of surrounding structures, and the dispersion of the exhaust gases. In addition, consideration must also be given for plume dispersion in case of possible emission ignition failure. Industrial flares are normally sized for a maximum heat intensity of 1,500-2,000 Btu/hr-ft^2 when flaring at their maximum design rates.[1,2] At this heat intensity level, workers can remain in the area of the flare for a limited period only. If, however, operating personnel are required to remain in the unit area performing their duties, the recommended design flare radiation level excluding solar radiation is 500 Btu/hr-ft^2.[1] The intensity of solar radiation is in the range of 250-330 Btu/hr-ft^2.[1] Flare height may also be determined by the need to safely disperse the vent gas in case of flameout. The height in these cases would be based on dispersion modeling for the particular installation conditions and is not addressed here. The minimum flare height normally used is 30 feet.[5] Equation (1.6) by Hajek and Ludwig may be used to determine the minimum distance, L, required from the center of the flare flame and a point of exposure where thermal radiation must be limited.[1]

$$L^2 \ (\mathrm{ft}^2) = \frac{\tau \ f \ R}{4 \ \pi \ K} \tag{1.6}$$

where

J	=	fraction of heat intensity transmitted
f	=	fraction of heat radiated
R	=	net heat release (Btu/hr)
K	=	allowable radiation (500 Btu/hr-ft^2)

The conservative design approach used here ignores wind effects and calculates the distance assuming the center of radiation is at the base of the flame (at the flare tip), not in the center. It is also assumed that the location where thermal radiation must be limited is at the base of the flare. Therefore, the distance, L, is equal to the required flare stack height (which is a minimum of 30 feet). The f factor allows for the fact that not all the heat released in a flame can be released as radiation. Heat transfer is propagated through three mechanisms: conduction, convection, and radiation. Thermal radiation may be either absorbed, reflected, or transmitted. Since the atmosphere is not a perfect vacuum, a fraction of the heat radiated is not transmitted due to atmospheric absorption (humidity, particulate matter). For estimating purposes, however, assume all of the heat radiated is transmitted (i.e., $r = 1$). Table 1.2 is a summary of heat radiated from various gaseous diffusion flames:[1]

Table 1.2: Heat from Various Gaseous Difusion Flames

Gas	Flare Tip Diameter (in)	Fraction of Heat Radiated (f)
Hydrogen	<1	.10
	1.6	.11
	3.3	1.6
	8.0	1.5
	16.0	1.7
Butane	<1	.29
	1.6	.29
	3.3	.29
	8.0	.28
	16.0	.30
Methane	<1	.16
	1.6	.16
	3.3	.15
Natural Gas	8.0	.19
	16.0	.23

In general, the fraction of heat radiated increases as the stack diameter increases. If stream-specific data are not available, a design basis of $f = 0.2$ will give conservative results.[4] The heat release, R, is calculated from the flare gas flow rate, W, and the net heating value, B_v, as follows:

$$R\left(\frac{\text{Btu}}{\text{hr}}\right) = W\left(\frac{\text{lb}}{\text{hr}}\right) B_v\left(\frac{\text{Btu}}{\text{lb}}\right) \tag{1.7}$$

1.3.4 Purge Gas Requirement

The total volumetric flow to the flame must be carefully controlled to prevent low flow flashback problems and to avoid flame instability. Purge gas, typically natural gas, N_2, or CO_2, is used to maintain a minimum required positive flow through the system. If there is a possibility of air in the flare manifold, N_2, another inert gas, or a flammable gas must be used to prevent the formation of an explosive mixture in the flare system. To ensure a positive flow through all flare components, purge gas injection should be at the farthest upstream point in the flare transport piping.

The minimum continuous purge gas required is determined by the design of the stack seals, which are usually proprietary devices. Modern labyrinth and internal gas seals are stated to require a gas velocity of 0.001 to 0.04 ft/sec (at standard conditions).[6, 7, 8, 9, 10] Using the conservative value of 0.04 ft/sec and knowing the flare diameter (in), the annual purge gas volume, F_{pu}, can be calculated:

$$\begin{aligned} F_{pu}\left(\frac{Mscf}{\text{yr}}\right) &= \left(0.04\ \frac{\text{ft}}{\text{sec}}\right)\left(\frac{\frac{\pi D^2}{4}}{144}\ \text{ft}^2\right)\left(3{,}600\ \frac{\text{sec}}{\text{hr}}\right)\left(8{,}760\ \frac{\text{hr}}{\text{yr}}\right) \\ &= 6.88 D^2 \left(\frac{Mscf}{\text{yr}}\right) \end{aligned} \tag{1.8}$$

There is another minimum flare tip velocity for operation without burn lock or instability. This minimum velocity is dependent on both gas composition and diameter and can range from insignificant amounts on small flares to 0.5 ft/sec on greater than 60-inch diameter units.[5]

Purge gas is also required to clear the system of air before startup, and to prevent a vacuum from pulling air back into the system after a hot gas discharge is flared. (The cooling of gases within the flare system can create a vacuum.) The purge gas consumption from these uses is assumed to be minor.

1.3.5 Pilot Gas Requirement

The number of pilot burners required depends on flare size and, possibly, on flare gas composition and wind conditions. Pilot gas usage is a function of the number of pilot burners required to ensure positive ignition of the flared gas, of the design of the pilots, and of the mode of operation. The average pilot gas consumption based on an energy-efficient model is 70 scf/hr (of typical 1000 Btu per scf gas) per pilot burner.[6, 7, 8, 9, 10] The number of pilot burners, N, based on flare size is:[6, 7, 8, 9, 10]

Table 1.3: Number of Burners by Flam Tip Diameter

Flare Tip Diameter (in)	Number of Pilot Burners (N)
1-10	1
12-24	2
30-60	3
>60	4

The annual pilot gas consumption, F_{pi} is calculated by:

$$F_{pi}\left(\frac{\text{Mscf}}{\text{yr}}\right) = \left(70\ \frac{\text{scf}}{\text{hr}}\right)(N)\left(8{,}760\ \frac{\text{hr}}{\text{yr}}\right) = \left(613\ \frac{\text{scf}}{\text{yr}}\right) N \qquad (1.9)$$

1.3.6 Steam Requirement

The steam requirement depends on the composition of the vent gas being flared, the steam velocity from the injection nozzle, and the flare tip diameter. Although some gases can be flared smokelessly without any steam, typically 0.01 to 0.6 pound of steam per pound of flare gas is required.[6, 7, 8, 9, 10] The ratio is usually estimated from the molecular weight of the gas, the carbon-to-hydrogen ratio of the gas, or whether the gas is saturated or unsaturated. For example, olefins, such as propylene, require higher steam ratios than would paraffin hydrocarbons to burn smokelessly.[2]

In any event, if a proprietary smokeless flare is purchased, the manufacturer should be consulted about the minimum necessary steam rate. A small diameter flare tip (less than 24 inches) can use steam more effectively than a large diameter tip to mix air into the flame and promote turbulence.[2] For a typical refinery, the average steam requirement is typically 0.25 lb/lb, with this number increasing to 0.5 lb/lb in chemical plants where large quantities of unsaturated hydrocarbons are flared.[10]

For general consideration, the quantity of steam required, S, can be assumed to be 0.4 pounds of steam per pound of flare gas, W Using a 0.4 ratio, the amount of steam required is:

$$S\left(\frac{\text{lbs}}{\text{yr}}\right) = \left(0.4\,\frac{\text{lb steam}}{\text{lb flare gas}}\right)\left(W\,\frac{\text{lb}}{\text{yr}}\right)\left(8{,}760\,\frac{\text{hr}}{\text{yr}}\right) \tag{1.10}$$

Operating a flare at too high a steam-to-gas ratio is not only costly, but also results in a lower combustion efficiency and a noise nuisance. The capacity of a steam-assisted flare to burn smokelessly may be limited by the quantity of steam that is available.

1.3.7 Knock-out Drum

As explained previously, the knock-out drum is used to remove any liquids that may be in the vent stream. Two types of drums are used: horizontal and vertical. The economics of vessel design influences the choice between a horizontal and a vertical drum. When a large liquid storage vessel is required and the vapor flow is high, a horizontal drum is usually more economical. Vertical separators are used when there is small liquid load, limited plot space, or where ease of level control is desired. It is assumed here that the drum is not sized for emergency releases and that liquid flow is minimal. Flares designed to control continuous vent streams generally have vertical knockout drums, whereas emergency flares typically have horizontal vessels. The procedure described below applies to vertical drums exclusively. A typical vertical knock-out drum is presented in Figure 1.2.

Liquid particles will separate when the residence time of the vapor is greater than the time required to travel the available vertical height at the dropout velocity of the liquid particles, *i.e.*, the velocity is less than the dropout velocity. In addition, the vertical gas velocity must be sufficiently low to permit the liquid droplets to fall. Since flares are designed to handle small-sized liquid droplets, the allowable vertical velocity is based on separating droplets from 300 to 600 micrometers in diameter.[1] The dropout velocity, U, of a particle in a stream, or the maximum design vapor velocity, is calculated as follows:[11]

$$U\left(\frac{\text{ft}}{\text{sec}}\right) = G\sqrt{\frac{\rho_l - \rho_v}{\rho_v}} \tag{1.11}$$

where

G	=	design vapor velocity factor
p_l and p_v	=	liquid and vapor densities, lb/ft^3

Note that in most cases,

$$\frac{\rho_l - \rho_v}{\rho_v} \approx \frac{\rho_l}{\rho_v} \tag{1.11a}$$

The design vapor velocity factor, G, ranges from 0.15 to 0.25 for vertical gravity separators at 85% of flooding.[11]

Once the maximum design vapor velocity has been determined the minimum vessel cross-sectional area, A, can be calculated by:

$$A\ (\mathrm{ft}^2) = \frac{Q_a \left(\frac{\mathrm{ft}}{\mathrm{min}}\right)}{\left(60\ \frac{\mathrm{sec}}{\mathrm{min}}\right)\left(U\ \frac{\mathrm{ft}}{\mathrm{sec}}\right)} \tag{1.12}$$

where Q_n is the vent stream flow in actual ft³/min, or Q adjusted to the vent stream temperature and pressure.

The vessel diameter, d_{min}, is then calculated by:

$$d_{\mathrm{min}} = \sqrt{\frac{4}{\pi} A} \tag{1.13}$$

In accordance with standard head sizes, drum diameters in 6-inch increments are assumed so:

$$d = d_{\mathrm{min}} \ \left(\textit{rounded to the next largest size}\right) \tag{1.14}$$

Some vertical knockout drums are sized as cyclones and utilize a tangential inlet to generate horizontal separating velocities. Vertical vessels sized exclusively on settling velocity (as in the paragraph above) will be larger than those sized as cyclones.[5]

The vessel thickness, t, is determined from the diameter as showen in Table 1.4 [15]. Proper vessel height, h, is usually determined based on required liquid surge volume. The calculated height is then checked to verify that the height-to-diameter ratio is within the economic range of 3 to 5.[11] For small volumes of liquid, as in the case of continuous VOC vent control, it is necessary to provide more liquid surge than is necessary to satisfy the h/d > 3 condition. So for purposes of flare knock-out drum sizing:

$$h = 3d \tag{1.15}$$

Table 1.4: Vessel Thickness based on Diameter

Diameter, *d* (inches)	Thickness, *t* (inches)
d<36	0.25
36<d<72	0.37
72<d<108	50.5
108<d<144	0.75
d>144	1.0

1.3.8 Gas Mover System

The total system pressure drop is a function of the available pressure of the vent stream, the design of the various system components, and the flare gas flow rate. The estimation of actual pressure drop requirements involves complex calculations based on the specific system's vent gas properties and equipment used. For the purposes of this section, however, approximate values can be used. The design pressure drop through the flare tip can range from 0.1 to 2 psi with the following approximate pressure drop relationships:[5] The total system pressure drop ranges from about 1 to 25 psi.[5]

Table 1.5: Design Pressure Losses through the Flare Tip

Equipment	Approximate Pressure Loss
Gas seal:	1 to 3 times flare tip pressure drop
Stack:	0.25 to 2 times flare tip pressure drop
Liquid seal and Knock out drum:	1 to 1.5 times flare tip pressure drop *plus* pressure drop due to liquid depth in the seal, which is normally 0.2 to 1.5 psi.
Gas collection system:	calculated based on diameter, length, and flow. System is sized by designer to utilize the pressure drop available and still leave a pressure at the stack base of between 2 and 10 psi.

1.4 Estimating Total Capital Investment

The capital costs of a flare system are presented in this section and are based on the design/sizing procedures discussed in Section 7.3. The costs presented are in September 2000 dollars.[1] The capital costs for this Chapter were updated through vender contacts in the summer of 2000. The costs were updated by sending vendors tables and graphs of previous cost equations and asking for updated information.

Vendors reported that costs had not increased subastantially since 1990, the primary reasons cited for stable prices ere increased competitions and lower steel prices. One vendor reported slight price increases over the period and another reported slight price decreases. Vendors agreed that the costs developed in 1990 reflected current market conditions. Items not such as platforms and ladders could result in some variation around these prices. Based on the information supplied by the vendors, the 1990 prices are carried forward for the year 2000 and are presented in Tables 1.6 to 1.8 and Figures 1.5 to 1.7. [2][7]

Total capital investment, TCI, includes the equipment costs, EC, for the flare itself, the cost of auxiliary equipment, the cost of taxes, freight, and instrumentation, and all direct and indirect installation costs.

The capital cost of flares depends on the degree of sophistication desired (i.e., manual vs automatic control) and the number of appurtenances selected, such as knock-out drums, seals, controls, ladders, and platforms. The basic support structure of the flare, the size and height, and the auxiliary equipment are the controlling factors in the cost of the flare. The capital investment will also depend on the availability of utilities such as steam, natural gas, and instrument air.

The total capital investment is a battery limit cost estimate and does not include the provisions for bringing utilities, services, or roads to the site, the backup facilities, the land, the research and development required, or the process piping and instrumentation interconnections that may be required in the process generating the waste gas. These costs are based on a new plant installation; no retrofit cost considerations such as demolition, crowded construction working conditions, scheduling construction with production activities, and long interconnecting piping are included. These factors are so site-specific that no attempt has been made to provide their costs.

1.4.1 Equipment Costs

Flare vendors were asked to provide budget estimates for the spectrum of commercial flare sizes. These quotes [6, 7, 8, 9, 10] were used to develop the equipment cost correlations for flare units, while the cost equations for the auxiliary equipment were based on references [12] and

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[1]For information on escalating these prices to more current dollars, refer to the EPA report Escalation Indexes for Air Pollution Control Costs and updates thereto, all of which are installed on the OAQPS Technology Transfer Network (CTC Bulletin Board).

[13] (knock-out drums) and [14] and [15] (piping). The expected accuracy of these costs is ± 30% (i.e., "study" estimates). Keeping in mind the height restrictions discussed in Section 7.2.4, these cost correlations apply to flare tip diameters ranging from 1 to 60 inches and stack heights ranging from 30 to 500 feet. The standard construction material is carbon steel except when it is standard practice to use other materials, as is the case with burner tips.

The flare costs, C_F presented in Equations 1.16 through 1.18 are calculated as a function of stack height, L (ft) (30 ft minimum), and tip diameter, D (in), and are based on support type as follows:

Self Support Group:

$$C_F\ (\$) = (78.0 + 9.14D + 0.749L)^2 \tag{1.16}$$

Guy Support Group:

$$C_F\ (\$) = (103 + 8.68D + 0.470L)^2 \tag{1.17}$$

Derrick Support Group:

$$C_F\ (\$) = (76.4 + 2.72D + 1.64L)^2 \tag{1.18}$$

The equations are least-squares regression of cost data provided by different vendors. It must be kept in mind that even for a given flare technology (i.e., elevated, steam-assisted), design and manufacturing procedures vary from vendor to vendor, so that costs may vary. Once a study estimate is completed, it is recommended that several vendors be solicited for more detailed cost estimates.

Each of these costs includes the flare tower (stack) and support, burner tip, pilots, utility (steam, natural gas) piping from base, utility metering and control, liquid seal, gas seal, and galvanized caged ladders and platforms as required. Costs are based on carbon steel construction, except for the upper four feet and burner tip, which are based on 310 stainless steel.

The gas collection header and transfer line requirements are very site specific and depend on the process facility where the emission is generated and on where the flare is located. For the purposes of estimating capital cost it is assumed that the transfer line will be the same diameter as the flare tip[6] and will be 100 feet long. Most installations will require much more extensive piping, so 100 feet is considered a minimum.

The costs for vent stream piping, C_p, are presented separately in Equation 1.19 or 1.20 and are a function of pipe, or flare, diameter D.[15]

$$C_p\ (\$) = 127 D^{1.21}\ (where\ 1'' < D < 24'') \qquad (1.19)$$

$$C_p\ (\$) = 139 D^{1.07}\ (where\ 30'' < D < 60'') \qquad (1.20)$$

The costs, C_p, include straight, Schedule 40, carbon steel pipe only, are based on 100 feet of piping, and are directly proportional to the distance required.

The costs for a knock-out drum, C_K, are presented separately in Equation 7.22 and are a function of drum diameter, d (in), and height, h (in).[12, 13]

$$C_K\ (\$) = 14.2\ [dt\ (h + 0.812 d)\ ]^{0.737} \qquad (1.21)$$

where t is the vessel thickness, in inches, determined based on the diameter.

Flare system equipment cost, EC, is the total of the calculated flare, knock-out drum, and piping costs.

$$EC\ (\$) = C_F + C_K + C_p \qquad (1.22)$$

Purchased equipment costs, PEC, is equal to equipment cost, EC, plus factors for ancillary instrumentation (i.e., control room instruments) (.10), sales taxes (0.03), and freight (0.05) or,

$$PEC\ (\$) = EC\ (1 + 0.10 + 0.03 + 0.05) = 1.18\ EC \qquad (1.23)$$

1.4.2 Installation Costs

The total capital investment, TCI, is obtained by multiplying the purchased equipment cost, PEC, by an installation factor of 1.92.

$$TCI\ (\$) = 1.92\ PEC \qquad (1.24)$$

These costs were determined based on the factors in Table 1.6. The bases used in calculating annual cost factors are given in Table 1.5. These factors encompass direct and indirect installation costs. Direct installation costs cover foundations and supports, equipment handling and erection, piping, insulation, painting, and electrical. Indirect installation costs cover engineering, construction and field expenses, contractor fees, start-up, performance testing, and contingencies. Depending on the site conditions, the installation costs for a given flare could deviate significantly from costs generated by these average factors. Vatavuk and Neveril provide some guidelines for adjusting the average installation factors to account for other-than-average installation conditions.[1]

The use of steam as a smoke suppressant can represent as much as 90% or more of the total direct annual costs.

Table 1.6: Self-Supporting Flare Costs

D (Diameter in Inches)	Hf (Hight in Feet)	Year 2000 (In Dollars)
12	30	$44,163
12	40	$47,367
12	50	$50,684
12	60	$54,112
12	70	$57,653
12	80	$61,306
12	90	$65,071
12	100	$68,948
24	30	$102,291
24	40	$107,138
24	50	$112,098
24	60	$117,169
24	70	$122,353
24	80	$127,649
24	90	$133,057
24	100	$138,578

Figure 1.5: Capital Costs of Self-supporting Flares for 12 in. and 24 in. Diameters

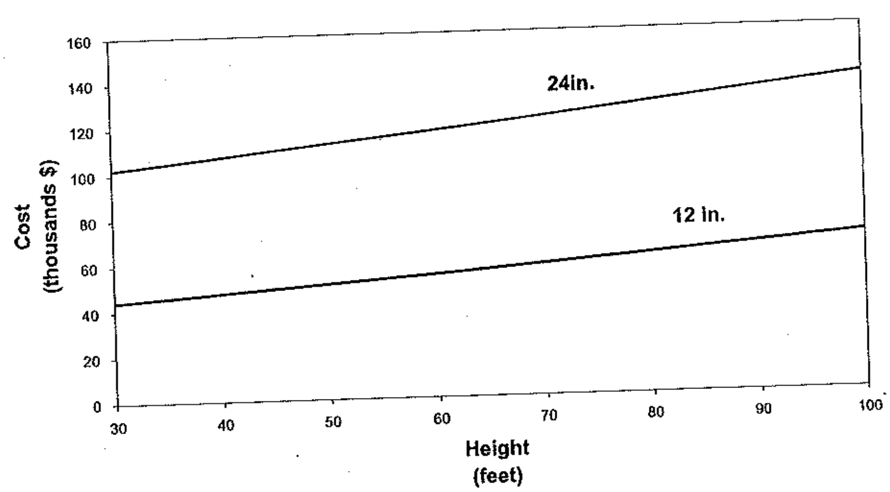


Table 1.7: Guy-Supported Flare Costs

Df (Diameter in Inches)	Hf (Height in Feet)	Year 2000 (In Dollars)
24	50	$112,104
24	100	$128,393
24	150	$145,787
24	200	$164,284
24	250	$183,887
24	300	$204,593
24	250	$183,887
24	400	$249,320
24	450	$273,341
24		
48	50	$295,001
48	100	$321,081
48	150	$348,265
48	200	$376,554
48	250	$405,947
48	300	$436,445
48	250	$405,947
48	300	$436,445
48	250	$405,947
48	400	$500,754
48	450	$534,566

Figure 1.6: Captial Costs of Guy-Supported Flares for 24 in. and 48 in. Diameters

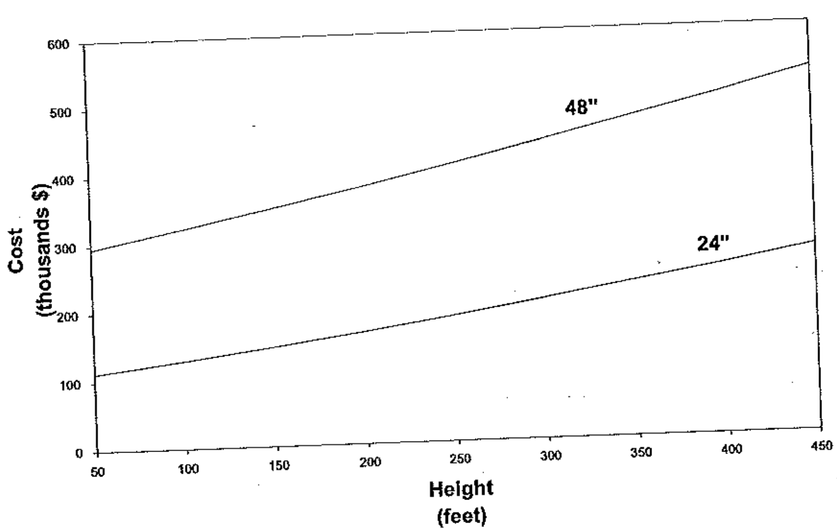
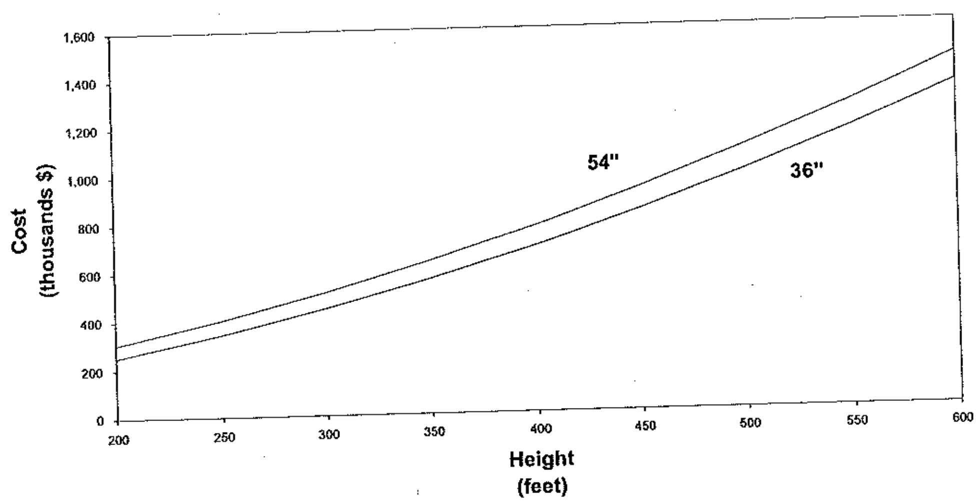


Table 1.8: Derrick Supported Flare Costs

Df (Diameter in Inches)	Hf (Height in Feet)	Year 2000 (In Dollars)
36	200	$252,325
36	250	$341,430
36	300	$443,982
36	350	$559,983
36	400	$689,431
36	450	$832,328
36	500	$988,672
36	550	$1,158,465
36	600	$1,341,705
54	200	$303,910
54	250	$401,044
54	300	$511,625
54	350	$635,655
54	400	$773,133
54	450	$924,059
54	500	$1,088,433
54	550	$1,266,255
54	600	$1,457,525

Figure 1.7: Captial Costs of Derrick-Supported Flares for 36 in. and 54 in. Diameters



1.5 Estimating Total Annual Costs

The total annual cost, TAC, is the sum of the direct and indirect annual costs. The bases used in calculating annual cost factors are given in Table 1.2

1.5.1 Direct Annual Costs

Direct annual costs include labor (operating and supervisory), maintenance (labor and materials), natural gas, steam, and electricity. Unless the flare is to be dedicated to one vent stream and specific on-line operating factors are known, costs should be calculated based on a continuous operation of 8,760 hr/yr and expressed on an annual basis. Flares serving multiple process units typically run continuously for several years between maintenance shutdowns.

Operating labor is estimated at 630 hours annually.[3] A completely manual system could easily require 1,000 hours. A standard supervision ratio of 0.15 should be assumed. Maintenance labor is estimated at 0.5 hours per 8-hour shift. Maintenance materials costs are assumed to equal maintenance labor costs. Flare utility costs include natural gas, steam, and electricity.

Flare systems can use natural gas in three ways: in pilot burners that fire natural gas, in combusting low Btu vent streams that require natural gas as auxiliary fuel, and as purge gas. The total natural gas cost, C_f, to operate a flare system includes pilot, C_{pi}, auxiliary fuel, C_a, and purge costs, C_{pu}:

$$C_f\left(\frac{\$}{yr}\right) = C_{pi} + C_a + C_{pu} \tag{1.25}$$

where, C_{pi} is equal to the annual volume of pilot gas, F_{pi}, multiplied by the cost per scf, $Cost_{fuel}$:

$$C_{pi}\left(\frac{\$}{\mathrm{yr}}\right) = \left(F_{pi}\ \frac{\mathrm{scf}}{\mathrm{yr}}\right)\left(Cost_{fuel}\ \frac{\$}{\mathrm{scf}}\right) \tag{1.26}$$

C_a and C_{pu} are similarly calculated.

Steam cost (C_s) to eliminate smoking is equal to the annual steam consumption, multiplied by the cost per lb, $Cost_{Stream}$:

$$C_s\left(\frac{\$}{\mathrm{yr}}\right) = \left(8{,}760\ \frac{\mathrm{hr}}{\mathrm{yr}}\right)\left(S\ \frac{\mathrm{lb}}{\mathrm{hr}}\right)\left(Cost_{steam}\ \frac{\mathrm{lb}}{\mathrm{hr}}\right) \tag{1.27}$$

1.5.2 Indirect Annual Costs

The indirect (fixed) annual costs include overhead, capital recovery, administrative (G & A) charges, property taxes, and insurance. Suggested indirect annual cost factors are presented in Table 1.9.

Overhead is calculated as 60% of the total labor (operating, maintenance, and supervisory) and maintenance material costs. Overhead cost is discussed in Section 1 of this Manual.

Table 1.9: Capital Cost Factors for Flare Systems

Cost Item	Factor
Direct Costs	
Purchased equipment costs	
Flare system, EC	As estimated, A
Instrumentation	0.10 A
Sales taxes	0.03 A
Freight	0.05 A
Purchased equipment cost, PEC	B = 1.18 A
Direct installation costs	
Foundations & supports	0.12 B
Handling & erection	0.40 B
Electrical	0.01 B
Piping	0.02 B
Insulation	0.01 B
Painting	0.01 B
Direct installation costs	0.57 B
Site preparation	
As required, SP	
Buildings	
As required, Bldg.	
Total Direct Costs, DC	1.57 B + SP + Bldg.
Indirect Annual Costs, DC	
Engineering	0.10 B
Construction and Field expenses	0.10 B
Contractor fees	0 B
Start-up	0.01 B
Performance test	0.01 B
Contingencies	0.03 B
Total Indirect Costs, IC	0.35 B
Total Capital Investment = DC + IC	1.92 B + SP + Bldg.

The system capital recovery cost, CRC, is based on an estimated 15-year equipment life. (See Section 1 of this Manual for a thorough discussion of the capital recovery cost and the variables that determine it.) For a 15-year life and an interest rate of 7%, the capital recovery factor is 0.1098. The system capital recovery cost is the product of the system capital recovery factor, CRF, and the total capital investment, TCI, or:

$$CRC\left(\frac{\$}{\text{yr}}\right) = CRF \times TCI = 0.1098 \times TCI \qquad (1.28)$$

As shown in Table 1.10, G & A, taxes, and insurance can be estimated at 2%, 1%, and 1% of the total capital investment, TCI, respectively.

Table 1.10: Suggested Annual Cost Factors for Flare Systems

Cost Item	Factor
Direct Annual Costs, DC	
Operating labor{3}	
Operator	630 man-hours/year
Supervisor	15% of operator
Operating materials	-
Maintenance	
Labor	½ hour per shift
Material	100% of maintenance labor
Utilities	
Electricity	All utilities equal to:
Purge gas	(Consumption rate) x
Pilot gas	(Hours/yr) x (unit cost)
Auxiliary fuel	
Steam	
Indirect Annual Costs, IC	
Overhead	60% of total labor and material costs
Administrative charges	2% of Total Capital Investment
Property tax	1% of Total Capital Investment
Insurance	1% of Total Capital Investment
Capital recovery[a]	0.1315 x Total Capital Investment
Total Annual Cost	Sum of Direct and Indirect Annual Costs

[a]See Chapter 2.

1.6 Example Problem

The example problem described in this section shows how to apply the flare sizing and costing procedures to the control of a vent stream associated with the distillation manufacturing of methanol.

1.6.1 Required Information for Design

The first step in the design procedure is to determine the specifications of the vent gas to be processed. The minimum information required to size a flare system for estimating costs are the vent stream:

Volumetric or mass flow rate
Heating value or chemical composition
Temperature
System pressure
Vapor and liquid densities

In addition the following are needed to calculate direct annual costs.

Labor costs
Fuel costs
Steam costs

Vent stream parameters and cost data to be used in this example problem are listed in Table 1.11.

1.6.2 Capital Equipment

The first objective is to properly size a steam-assisted flare system to effectively destroy 98% of the VOC (methanol) in the vent gas stream. Using the vent stream parameters and the design procedures outlined in Section 1.3, flare and knock-out drum heights and diameters can be determined. Once equipment has been specified, the capital costs can be determined from equations presented in Section 1.4.1.

Table 1.11: Example Problem Data

Vent Stream Parameters	
Flow rate	63.4 acfm[a]
	399.3 lb/hr
Heat content	449 Btu/scf[b]
System pressure	10 psig[c]
Temperature	90 °F
Liquid density[17]	49.60 lb/ft^3[d]
Vapor density[17]	0.08446 lb/ft^3[d]
Cost Data (March 1990)[18,19]	
Operating hours	8,760 hrs/yr
Natural gas	3.03 $/1000 scf
Steam	4.65 $/1000 lbs
Operating labor	15.64 $/hr
Maintenance labor	17.21 $/hr

[a]Measured at *flare tip*. Flow rate has been adjusted to account for drop in pressure from 10 psig at source to 1 psig at flare tip.
[b]Standard conditions: 77°F, 1 atmosphere.
[c]Pressure at source (gas collection point). Pressure at flare tip is lower: 1 psig.
[d]Measured at standard conditions.

1.6.2.1 Equipment Design

The first step in flare sizing is determining the appropriate flare tip diameter. Knowing the net (lower) heating value of the vent stream, the maximum allowed velocity can be calculated from the Federal Register requirements. Since the heating value is in the range of 300 to 1,000 Btu/scf, the maximum velocity, V_{max}, is determined by Equation 1.1.

$$\log_{10} V_{max} = \frac{449 \frac{\text{Btu}}{\text{scf}} + 1{,}214}{852} = 1.95$$

$$V_{max} = 89.5 \frac{\text{ft}}{\text{sec}}$$

Because the stream heating value is above 300 Btu/scf, no auxiliary fuel is required. Hence, Q_{tot} equals the vent stream flow rate. Based on Q_{tot} and V_{max}, the flare tip diameter can be calculated using Equation 1.5.

$$D_{min} = 1.95 \sqrt{\frac{63.4\ scfm}{89.5\left(\frac{ft}{sec}\right)}} = 1.64\ in$$

The next largest commercially available standard size of 2 inches should be selected for D.

The next parameter to determine is the required height of the flare stack. The heat release from the flare is calculated using Equation 1.7.

$$R\ \frac{Btu}{hr} = W\ \frac{lb}{hr}\ B_v\ \frac{Btu}{lb}$$

First the heat of combustion, or heating value, must be converted from Btu/scf to Btu/lb. The vapor density of the vent stream at standard temperature and pressure is 0.08446 lb/scf.

So,

$$B_v = \frac{449\left(\frac{Btu}{scf}\right)}{0.08446\left(\frac{lb}{scf}\right)} = 5316\left(\frac{Btu}{lb}\right)$$

and,

$$R = \left(399.3\ \frac{\text{lb}}{\text{hr}}\right)\left(5{,}316\ \frac{\text{Btu}}{\text{lb}}\right) = 2{,}123{,}000\ \frac{\text{Btu}}{\text{hr}}$$

Substituting R and appropriate values for other variables into Equation 1.6:

$$L^2 = \frac{(1)\ (0.2)\ \left(2{,}123{,}000\ \frac{\text{Btu}}{\text{hr}}\right)}{4\pi\left(500\ \frac{\text{Btu}}{\text{hr-ft}^2}\right)} = 68\ \text{ft}^2$$

Resulting in:

$$L = 8.2\text{ft}$$

Assuming the smallest commercially available flare is 30 feet, the flare height is set to this value, L = 30 ft.

Next the knock-out drum must be sized. Assuming a design vapor velocity factor, G, of 0.20, and substituting the vapor and liquid densities of methanol into Equation 1.11 yields a maximum velocity of:

$$U = 0.20\sqrt{\frac{49.60 - 0.08446}{0.08446}} = 4.84\frac{\text{ft}}{\text{sec}}$$

Given a vent gas flow rate of 63.4 scfm, the minimum vessel cross-sectional, diameter is calculated by Equation 1.12:

$$A = \frac{63.4\text{acfm}}{(60)\frac{\text{sec}}{\text{min}}\ (4.84)\frac{\text{ft}}{\text{sec}}} = 0.218\ \text{ft}^2$$

This results in a minimum vessel diameter of:

$$d_{min} = 12\frac{in}{ft}\sqrt{\frac{4}{\pi}\left(0.218\,ft^2\right)} = 6.3\ in$$

The selected diameter, d, rounded to the next largest 6 inches is 12 inches. Using the rule of the height to diameter ratio of three gives a vessel height of 36 inches, or 3 feet.

1.6.2.2 Equipment Costs

Once the required flare tip diameter and stack height have been determined the equipment costs can be calculated. Since the height is 30 feet, the flare will be self-supporting. The costs are determined from Equation 1.16.

$$C_F = [78.0 + 9.14\ (2\text{ inches}) + 0.749\ (30\text{ ft})\ ]^2$$
$$= \$14{,}100$$

Knock-out drum costs are determined using Equation 7.21, where t is determined from the ranges Presented in Section 7.3.7. Substituting 0.25 for t:

$$C_K = 14.2\ [\ (12)\ (0.25)\ (36\ +\ 0.812\ (12)\ )\ ]^{0.737} = \$530$$

Transport piping costs are determined using Equation 1.19.

$$C_p = 127\ (2)^{1.21} = \$290$$

The total auxiliary equipment cost is the sum of the knock-out drum and transport piping costs, or: \$530 + \$290 = \$820.

The total capital investment is calculated using the factors given in Table 1.9. The calculations are shown in Table 1.12. Therefore:

$$PEC = 1.18 \times (14{,}920) = \$17{,}610$$

And:

$$TCI = 1.92 \times (17{,}610) = \$33{,}800$$

1.6.3 Operating Requirements

Operating labor is estimated at 630 hours annually with supervisory labor at 15% of this amount. Maintenance labor is estimated at 1/2 hour per shift. Maintenance material costs are assumed to be equal to maintenance labor costs.

As stated in Table 1.11, since the heat content of the example stream is above 300 Btu/scf no auxiliary fuel is needed. Natural gas is required, however, for purge and pilot gas. Purge gas requirements are calculated from Equation 1.8.

$$F_{pu} = 6.88\ (2\ in)^2 = 27.5\ \frac{Mscf}{yr}$$

Table 1.12: Capital Cost for Flare Systems - Example Problem

Cost Item	Cost
Diret Costs	
Purchased Equipment Costs	
Flare system (Self-supporting)	$14,100
Auxiliary Equipment*	820
Sum = A	$14,920
Instrumentation	1,490
Sales taxes	450
Freight	750
Purchased equipment cost, PEC	$17,610
Direct Installation Costs	
Foundations & Supports,	2,110
Handling & Erection	7,040
Electrical	180
Piping	350
Insulation	180
Painting	180
Direct Installation Costs	$10,040
Site Preparation	
Facilities and Buildings	
Total Direct Costs	**$27,650**
Indirect Annual Costs, DC	
Engineering	1,760
Construction and Field Expenses	1,760
Contractor Fees	1,760
Start-Up	180
Performance Test	180
Contingencies	530
Total Indirect Costs, IC	$6,170
Total Capital Investment = DC + IC	**$33,800**

[a] Asumed to be 6% of the flare system cost. For more information on the costing of auxiliary equipment, refer to Section 2 of the Manual.

Since the flare tip diameter is less than 10 inches, pilot gas requirements are based on one pilot burner, (see Section 1.3.5) and are calculated by Equation 1.9.

$$F_{pu} = 6.88\ (2\ in)^2 = 27.5\ \frac{Mscf}{yr}$$

When N = 1,

$$F_{pi} = 613\ (1) = 613\ \frac{Mscf}{yr}$$

Steam requirements are calculated from Equation 1.10. Inserting the methanol mass flow rate of 399.3 lb/hr yields:

$$S = \left(0.4\ \frac{lb\ steam}{lb\ flare\ gas}\right)\left(8760\frac{hr}{yr}\right)\left(399.3\frac{lb}{hr}\right) = 1{,}400\ \frac{lb}{hr}$$

1.6.4 Total Annual Costs

The sum of the direct and indirect annual costs yields a total annual cost of $61,800. Table 1.13 shows the calculations of the direct and indirect annual costs for the flare system as calculated from the factors in Table 1.10. Direct costs include labor, materials, and utilities. Indirect costs are the fixed costs allocated to the project, including capital recovery costs and such costs as overhead, insurance, taxes, and administrative charges.

Electrical costs of a mover system (fan, blower, compressor) would have to be included if the vent stream pressure was not sufficient to overcome the flare system pressure drop. In this example case, the pressure is assumed to be adequate.

Table 1.13: Annual Costs for Flare System Example problem

Cost Item	Calculations	Cost
Direct Annual Costs, DC		
Operating Labor		
Operator	$\frac{630\text{ h}}{\text{year}} \times \frac{\$15.64}{\text{h}}$	$ 9,850
Supervisor	15% of operator = 0.15 x 9,850	1,480
Operating materials		
Maintenance		
Labor	$\frac{0.5\text{ h}}{\text{shift}} \times \frac{\text{shift}}{8\text{ h}} \times \frac{8{,}760\text{h}}{\text{yr}} \times \frac{\$17.21}{\text{h}}$	9,420
Maintenance Material	100% of maintenance labor	9,420
Utilities		
Electricity		
Purge gas Inserting the methanol mass flow rate of 399.3 lb/hr yields:	$\frac{27.5\text{ Mscf}}{\text{yr}} \times \frac{\$3.03}{\text{Mscf}}$	80
Pilot gas	$\frac{613\text{ Mscf}}{\text{yr}} \times \frac{\$3.03}{\text{Mscf}}$	1,860
Steam	$\frac{1{,}400 \times 10^3\text{lb}}{\text{yr}} \times \frac{\$4.65}{10^3\text{lb}}$	6,510
Total DC (rounded)		$38,600
Indirect Annual Costs, IC		
Overhead	60% of total labor and material costs = 0.6(9,850 + 1,480 + 9,420 + 9,420)	18,100
Administrative charges	2% of Total Capital Investment = 0.02 ($33,800)	680
Property tax	1% of Total Capital Investment = 0.01 ($33,800)	340
Insurance	1% of Total Capital Investment = 0.01 ($33,800)	340
Capital recovery[a]	0.1098 x $33,800	3,710
Total IC (rounded)		23,200
Total Annual Cost (rounded)		$61,800

[a]The capital recovery cost factor, CRF, is a function of the flare equipment life and the opportunity cost of the capital (i.e. interest rate). For example, for a 15 year equipment life and 7% interest rate, CRF = 0.1098.

1.7 Acknowledgments

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- Peabody Engineering Corporation (Stamford, CT)
- Piedmont HUB, Incorporated (Raleigh, NC)

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[4] Letter from J. Keith McCartney (John Zink Co., Tulsa, OK) to William M. Vatavuk (U.S. Environmental Protection Agency, Research Triangle Park, NC), November 19, 1990.

[5] Letter from David Shore (Flaregas Corp., Spring Valley, NY) to William M. Vatavuk (U.S. Environmental Protection Agency, Research Triangle Park, NC), October 3, 1990.

[6] Letter from Pete Tkatschenko (NAO, Inc., Philadelphia, PA) to Diana Stone (Radian, Research Triangle Park, NC), May 2, 1990.

[7] Letter to Gary Tyler (Kaldair, Inc., Houston, TX) to Diana Stone (Radian, Research Triangle Park, NC), April 10, 1990.

[8] Letter from Zahir Bozai (Peabody Engineering Corp., Stamford, CT) to Diana Stone (Radian, Research Triangle Park, NC), May 7, 1990.

[9] Letter from James Parker (John Zink Co., Tulsa, OK) to Diana Stone (Radian, Research Triangle Park, NC), April 17, 1990.

[10] Letter from Nick Sanderson (Flaregas Corp., Spring Valley, NY) to Diana Stone (Radian, Research Triangle Park, NC), May 2, 1990.

[11] Wu, F.H., "Drum Separator Design, A New Approach," *Chemical Engineering*, April 2, 1984, pp. 74-81.

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[19] *Monthly Energy Review*, Energy Information Administration, Office of Energy Markets and End Use, U.S. Department of Energy, DOE-EIA-0035(90/12), February 1990.

TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

1. REPORT NO. 452/B-02-001	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE The EPA Air Pollution Control Cost Manual		5. REPORT DATE January, 2002
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Daniel Charles Mussatti		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Air Quality Standards and Strategies Division Innovative Strategies and Economics Group Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Director Office of Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES
Updates and revises EPA 453/b-96-001, OAQPS Control Cost Manual, fifth edition (in English only)

16. ABSTRACT
In Spanish, this document provides a detailed methodology for the proper sizing and costing of numerous air pollution control devices for planning and permitting purposes. Includes costing for volatile organic compounds (VOCs); particulate matter (PM); oxides of nitrogen (NOx); SO2, SO3, and other acid gasses; and hazardous air pollutants (HAPs).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Economics Cost Engineering cost Sizing Estimation Design	Air Pollution control Incinerators Absorbers Adsorbers Filters Condensers Electrostatic Precipitators Scrubbers	

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(Report)* Unclassified	21. NO. OF PAGES 1,400
	20. SECURITY CLASS *(Page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

ATTACHMENT 4

Callidus Email from Brian Duck

From: Duck, Brian [mailto:Brian.Duck@Honeywell.com]
Sent: Wednesday, May 11, 2011 11:14 AM
To: Joyner, Edward (Buddy), Celanese/US
Subject: RE: EPA Response

Buddy,

Even though the center steam is close to the exit of the tip there is no air inside the flare tip so it is not possible for the center steam to inspirate air into the flame. Also, the air assisted example in the EPA response isn't a good example because the air in an air assisted flare is also injected into the flame and is not inside the flare tip. In addition, the center steam is injected into the flare tip at a very low velocity that is too low to inspirate. We supply many flare systems in which steam is a part of the waste gas. Would this also be considered a steam assisted flare? The presence of steam injected into the tip through the center steam is no different than if the steam came from the process.

I have attached section 5.1.3 from API Standard 537, *Flare Details for General Refinery and Petrochemical Service*, for which I sat on the review committee and I also wrote a portion of the standard. It describes the difference between steam used for a steam assisted flare and center steam which is used to mitigate internal burning.

Please let me know if you have any questions.

Best regards,

Brian Duck

ATTACHMENT 5

API Standard 537

ATTACHMENT 6

MO-3 Vent Analysis

MO-3 Vent 5/10/11 16:30

EPA Requested Sampling

Sample collected in 3.8 L tedlar sampling bag

Non-Condensibles Anayses by Micro TCD-GC

Standard

	Area 1	Area 2	Area 3	Area 4	Average Area	mol%	Response Factor
Hydrogen	22412	22513	22430	22266	22405.25	23.19	0.001035025
Argon-O2	315757	319627	331540	316438	320840.5	1.53	4.76872E-06
Nitrogen	9989755	9992189	9994703	9982982	9989907	69.151	6.92209E-06
Carbon Monoxide	289071	288984	287334	288953	289027.5	2.01	6.95436E-06
Carbon Dioxide	753370	750520	748518	752603	751252.8	4.02	5.35106E-06
Methane	11188	11185	10918	10903	11048.5	0.099	8.96049E-06

MOIII Vent Sample

	Area 1	Area 2	Average Area	mol%
Hydrogen	22049	21932	21990.5	22.761
Argon-O2	247766	263876	255821	1.220
Nitrogen	9946638	9976932	9961785	68.956
Carbon Monoxide	22258	22138	22198	0.154
Carbon Dioxide	848804	847682	848243	4.539

Condensibles Analyses by FID-GC

Standard

	Area 1	Area 2	Average Area	mol%	Response Factor
Methane	3.57E+04	3.57E+04	3.57E+04	0.0304	8.51E-07
Methyl Formate	6.74E+05	6.50E+05	6.62E+05	0.746	1.13E-06
Methylal	9.82E+05	9.39E+05	9.61E+05	0.536	5.58E-07
Methanol	2.41E+05	2.31E+05	2.36E+05	0.312	1.32E-06

MOIII Vent Sample

	Area 1	Area 2	Average Area	mol%
Methane	3.29E+03	3386.971	3.34E+03	0.003
Methyl Formate	9.73E+05	1.01E+06	9.92E+05	1.096

Methylal	1.13E+06	1.18E+06	1.16E+06	0.630	
Methanol	7.40E+04	7.66E+04	7.53E+04	0.098	
1,3-Dioxolane	7.04E+04	7.38E+04	7.21E+04	0.095	used MeOH response factor
Benzene	8.59E+05	9.02E+05	8.81E+05	0.388	used MeOH response factor (divided by 3 since bei
Methoxymethylal	1.47E+05	1.54E+05	1.50E+05	0.199	used MeOH response factor
Others (8 tiny peaks)	4267.479	4108.095	4.19E+03	0.006	estimated using MeOH response factor

Composition Results

	non-normalized mole%	normalized mole %
Hydrogen	22.761	**22.728**
Argon-O2	1.220	**1.218**
Nitrogen	68.956	**68.856**
Carbon Monoxide	0.154	**0.154**
Carbon Dioxide	4.539	**4.532**
Methane	0.003	**0.003**
Methyl Formate	1.096	**1.094**
Methylal	0.630	**0.630**
Methanol	0.098	**0.098**
Benzene	0.388	**0.388**
1,3-Dioxolane	0.095	**0.095**
Methoxymethylal	0.199	**0.198**
Others	0.006	**0.006**
Totals	100.145	**100.000**
HCHO , ppmw	0.001	

Note: HCHO was determined by slowly scrubbing 120 mL of gas sample with 10 grams of water. HCHO determined by acetylacetone method. Assumed gas density at 1.

Note: Others were estimated by combining areas and using the MeOH response factor

Note: GCMS analyses showed the presence of Methanol, Methyl Format Methylal, Dioxolane, Methoxymethylal, benzene, and slight traces of 2-butanone, 1,1-dimethoxyethane, trioxane, and formaldehyde

ızene is approximately 3 times more sensitive than MeOH by GC-FID)

ATTACHMENT 7

Hoechst Celanese 5-6-11 Callidus Letter

Honeywell

CALLIDUS
TECHNOLOGIES

Automation & Control Solutions
Honeywell
7130 South Lewis Avenue
Suite 335
Tulsa, OK 74136

Main Line: 918-496-7599

May 6, 2011

Hoechst Celanese
Hwy. 77 South
P.O. Box 428
Bishop, TX 78343

RE: Your P.O. Number 4500000897
Flares M03 and M04
Callidus Work Order No. F-6403

Attention: Mr. Buddy Joyner

Dear Mr. Joyner:

As stated in our letter dated December 8, 2000, it is the opinion of Callidus Technologies by Honeywell that the flares referred above are "un-assisted" for classification reasons. Steam-assisted flares are fitted with steam injection directly into the flame to inspirate and mix air into the flame for smoke control. If the heating value of the gas is too low, the flame can become over aerated and decrease the combustion efficiency of the flame. The flare tips (referred above) use steam to control flashback inside the tip and do not inspirate any air.

Please let us know if you have any questions.

Best regards,

B- Del

Brian Duck
Callidus Technologies by Honeywell

ATTACHMENT 8

Additional Mfg's Definition of Assisted Flare

Trinity Energy Solutions, Inc (excerpts from)

http://www.trinityenergysolutions.com/index.php?option=com_content&view=article&id=14&Itemid=14

Types of Flares

There are two general families of flare systems that Tornado works with: Utility Flares and Engineered Smokeless Flares.

Utility Flares

A Utility (non-assisted) flare is the most basic type of flare. The flare's height is calculated based on the radiation and dispersion flaring emissions at the ground that are caused by the combustion process. A utility flare tip's internal diameter is sized based on: The exit velocity of the flare, and the allowable pressure drop

Air-Assist Flares

Air Assisted Smokeless Combustion exists where air is added to the Waste Gas Stream at the tip of the Flare stack to eliminate smoking.

There are two different Air Assist Flare Types typically provided by Tornado:

1. Retrofit Air Assisted Flare

This type of air assisted flare is where Tornado takes an existing Utility Flare that is smoking and provides an external air duct, tip and blower to convert it to a smokeless air assisted flare.

High Pressure Gas-Assist Flares

The general principle behind gas-assisted flares is to introduce a high pressure gas to the waste steam just after exiting the flare tip to eliminate smoking. The addition of gas will increase the radiation produced by the flare, which may in turn add to the overall flare's required height to compensate. Let Tornado Technologies assist you with determining if gas assisted or air assisted flaring is the best choice to eliminate or prevent a smoking flare.

Steam Assist Flares

The general principle behind steam-assisted flares is to introduce high pressure steam to the waste gas steam just after exiting the flare tip.

Low- Pressure Gas- Assist

A low pressure gas assist maybe required when flaring acid/toxic gases with low heating values. The ring burner creates a flame curtain between the tip of the flare and the ignition point of the flare's flame front to ensure that any reactants do not escape without first hitting a flame. Thus 100% of the gas exiting the flare is given the required energy to combust.

Flaregas Corp (excerpts from) http://www.flaregas.com/elevated%20flares.html

AIR-ASSISTED SMOKELESS FLARES

Flaregas air assisted flares are co-axial, with the gas passing to the flare tip in the inner gas riser. The air for smokeless combustion is provided by low pressure air assist fans located at the base of the stack, and conducted to the flare tip in the annular space between the gas riser and the outer air duct. The outer air duct becomes the structural support for the stack, which can be self-supported, guy-supported or supported using a derrick structure - normally depending on the height of the flare

Zeeco Combustion and Environmental Soultions (excerpts from) http://www.zeeco.com/flares/flares_elevated_steam_qfs.php

Steam Assisted Zeeco's QFS Steam Assisted flare tip provides control of smoke in a flare system at an affordable cost. The design of the QFS steam injection nozzle minimizes the noise associated with steam injection. The proprietary QFS steam nozzle is designed using a number of injection ports to successfully reduce the steam injection noise to well below that of conventional steam assisted flare tips. Injection of steam at the flare tip exit point provides more than smokeless performance. The steam also "shapes" the flare flame in high wind conditions, eliminating the downwind flame impingement seen on many non-assisted flare tips. The steam also assists in lowering the radiation level at grade, by lowering the emissivity of the flare flame, and by providing an upward vector to stand the flame up in a crosswind.

In Zeeco's HCL flare tip design, the steam injection manifold is moved from the top of the flare tip to a point near the base of the flare tip. This moves the steam injection nozzles away from the heat of the flare flame, and into a position where a noise shroud can be added to muffle the jet noise from the steam injection. The HCL flare tip uses a system of internal steam / air tubes to route an air / steam mixture from the steam injection manifold up the interior of the flare tip and discharge this steam / air mixture directly into the gas column as it exits the flare tip. The steam and air mixture is injected directly into the flare gas at numerous points across the diameter of the flare tip, and not just from the perimeter as in most standard steam flare designs.

Air Assisted When smokeless flaring is desired and neither steam nor assist gas is available, blowers can be used to inject combustion air directly into the waste gas stream as it exits the flare tip. The ZEECO AF air assisted flare tip incorporates a proprietary design that splits the waste gas stream into several smaller streams at the top of the flare to increase the gas / air contact surface area and promote better mixing. This key design feature maximizes the waste gas / assist air mixing while minimizing the amount of forced air required and resultant blower horsepower. Forced air from the blowers and gas from the flare header are routed separately from the base of the flare stack to the top of the flare. At no point do the air and gas mix prior to leaving the flare tip, ensuring the safety of the system. In addition, with this design concept, any ZEECO AF air assisted flare can operate without the blowers being on and provide for safe disposal of the waste gases in the event of a power outage. The Series AF flare tip produces a superior quality flame, which stays erect during all atmospheric and flow conditions. Flame lick on the exterior of the flare and burnback inside the flare tip, are virtually eliminated by the forced air from the blowers, which create a strong upward velocity, making the impact from the wind minimal in shaping or moving the flame. The forced air also shortens the flame length and reduces radiation at grade by ensuring a very aerated mixture at the exit of the flare tip.

ATTACHMENT 9

Excerpt from Federal Register, May 4, 1998, page 24440 justice related issues as required by Executive Order 12898 (59 FR 7629, February 16, 1994). Because this action is not subject to notice-and-comment requirements under the Administrative Procedure Act or any other statute, it is not subject to the regulatory flexibility provisions of the Regulatory Flexibility Act (5 U.S.C. 601 *et seq.*). EPA's compliance with these statutes and Executive Orders for the underlying rule is discussed in the July 22, 1997, **Federal Register** document.

Pursuant to 5 U.S.C. 801(a)(1)(A), as added by the Small Business Regulatory Enforcement Fairness Act of 1996, EPA will submit a report containing this rule and other required information to the U.S. Senate, the U.S. House of Representatives and the Comptroller General of the General Accounting Office; however, in accordance with 5 U.S.C. 808(2), this rule is effective on May 4, 1998. This rule is not a "major rule" as defined in 5 U.S.C. 804(2).

This final rule only amends the effective date of the underlying rule; it does not amend any substantive requirements contained in the rule. Accordingly, to the extent it is available, judicial review is limited to the amended effective date.

Dated: April 22, 1998.

Carol Browner,

Administrator.

[FR Doc. 98–11542 Filed 5–1–98; 8:45 am]

BILLING CODE 6560–50–M

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 60 and 63

[AD–FRL–6003–7]

RIN 2060–AH94

Standards of Performance for New Stationary Sources: General Provisions; National Emission Standards for Hazardous Air Pollutants for Source Categories: General Provisions

AGENCY: Environmental Protection Agency (EPA).

ACTION: Direct final rule.

SUMMARY: This action amends the General Control Device Requirements applicable to flares in 40 CFR Part 60 which were issued as a final rule on January 21, 1986, and the Control Device Requirements applicable to flares in 40 CFR Part 63 which were issued as a final rule on March 16, 1994. This action amends existing specifications to permit the use of hydrogen-fueled flares. For additional information concerning comments, see the parallel proposal found in the Proposed Rules Section of this **Federal Register**.

DATES: This direct final rule is effective June 23, 1998 without further notice unless the Agency receives relevant adverse comments by June 3, 1998. Should the Agency receive such comments, it will publish a document withdrawing this rule. The incorporation by reference of certain publications listed in the rule is approved by the Director of the Federal Register as of June 23, 1998.

ADDRESSES: *Comments.* Comments should be submitted (in duplicate, if possible) to: Air and Radiation Docket and Information Center (6102), Attention Docket No. A–97–48 (see docket section below), Room M–1500, U.S. Environmental Protection Agency, 401 M Street S.W., Washington, D.C. 20460. The EPA requests that a separate copy also be sent to Mr. Robert Rosensteel (see **FOR FURTHER INFORMATION CONTACT** section for address). Comments may also be submitted electronically by following the instructions provided in the **SUPPLEMENTARY INFORMATION** section. No Confidential Business Information (CBI) should be submitted through electronic mail.

Docket. The official record for these amendments has been established under docket number A–97–48. A public version of this record, including printed, paper versions of electronic comments and data, which does not include any information claimed as CBI, is available for inspection between 8 a.m. and 4 p.m., Monday through Friday, excluding legal holidays. The official rulemaking record is located at the address in the **ADDRESS** section. Alternatively, a docket index, as well as individual items contained within the docket, may be obtained by calling (202) 260–7548 or (202) 260–7549. A reasonable fee may be charged for copying.

FOR FURTHER INFORMATION CONTACT: Mr. Robert Rosensteel, Emission Standards Division (MD–13), U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711, telephone number (919) 541–5608.

SUPPLEMENTARY INFORMATION:

Electronic Filing

Electronic comments and data can be sent directly to EPA at: a-and-r-docket@epamail.epa.gov. Electronic comments and data must be submitted as an ASCII file avoiding the use of special characters and any form of encryption. Comments and data will also be accepted on diskette in Word Perfect 5.1 file format or ASCII file format. All comments and data in electronic form must be identified by the docket number A–97–48. Electronic comments may be filed online at many Federal Depository Libraries.

Electronic Availability

This document is available in Docket No. A–97–48, or by request from the EPA's Air and Radiation Docket and Information Center (see **ADDRESSES**), and is available for downloading from the Technology Transfer Network (TTN), the EPA's electronic bulletin board system. The TTN provides information and technology exchange in various areas of emissions control. The service is free, except for the cost of a telephone call. Dial (919) 541–5742 for up to a 14,000 baud per second modem. For further information, contact the TTN HELP line at (919) 541–5384, from 1:00 p.m. to 5:00 p.m., Monday through Friday, or access the TTN web site at: www.epa.gov/ttn/oarpg/rules.html.

Regulated Entities

Entities affected by this direct final rule include:

Category	Examples of regulated entities
Industry	Synthetic Organic Chemical Manufacturing Industries; and Petroleum Refining Industries.

This table is not intended to be exhaustive, but rather provides a guide for readers regarding entities likely to be affected by this action. This table lists the types of entities that the EPA is now aware could potentially be affected by this action. Other types of entities not listed in the table could also be affected. If you have any questions regarding the applicability of this direct final rule to a particular entity, consult the person listed in the preceding **FOR FURTHER INFORMATION CONTACT** section.

The information presented in this preamble is organized as follows:

2. Destruction Efficiency

The measured mean destruction efficiencies and destruction efficiencies at the 95 percent confidence level are shown in Figure 1. All the measurements of destruction efficiencies at conditions more stable than lift off were above 99 percent. Further, control efficiencies greater than 98 percent were found at hydrogen contents below the lift off curve.

III. Rationale

A. The Need for Specifications for Hydrogen-Fueled Flares

The EPA is taking this action to amend 40 CFR 60.18 and 40 CFR 63.11 since the EPA sees the need to permit the use of hydrogen-fueled flares to meet the EPA control requirements. As discussed below, hydrogen has a lower heat content than organics commonly combusted in flares meeting the existing flare specifications and cannot, therefore, be used to satisfy current control requirements. However, since the combustion of hydrogen is different than the combustion of organics, and the test report demonstrates a destruction efficiency greater than 98 percent, the EPA believes that hydrogen-fueled flares meeting the specifications outlined in the amendments will achieve a control efficiency of 98 percent or greater. This level of control is equivalent to the level of control achieved by flares meeting the existing specifications. In addition to achieving the same destruction efficiency of VOC or organic HAP, the adoption of these amendments has the added advantage of reducing the formation of secondary pollutants; since the combustion of supplemental fuel would not be required by hydrogen-fueled flares to meet the existing flare specifications.

1. The Heat Content of Hydrogen

The heat content of a substance is a measure of the amount of energy stored within the bonds between atoms in each molecule of the substance. Hydrogen is a simple molecule consisting of two hydrogen atoms held together by weak, hydrogen bonds, thus resulting in a low heat content. In comparison, organic chemicals are larger chains (or rings) of carbons with hydrogens and other atoms attached to them. These molecules are held together with a combination of ionic, covalent and hydrogen bonds, which contain substantially more energy (i.e., higher heat content) than the hydrogen bond in the hydrogen molecule.

2. The Difference in Combustion Between Hydrogen and Organics

The first phenomenon to explain the difference in combustion between hydrogen and organics is related to the thermodynamics of the combustion reaction. In order for the hydrogen atom to react in the combustion/oxidation reaction, the weak hydrogen bond between the two hydrogen atoms must first be broken. Because there is less energy holding the hydrogen atoms together, less energy (heat) is required to separate them. Once the hydrogen bonds are broken, the hydrogen atoms are free to react in the combustion reaction.

The second phenomenon explaining the difference in combustion between hydrogen and organics is due to hydrogen's upper and lower flammability limits. The flammability limits are the minimum (lower) and maximum (upper) percentages of the fuel in a fuel-air mixture that can propagate a self-sustaining flame. The lower and upper flammability limits of hydrogen are 4.0 and 74.2 percent, respectively, which is the second widest range of lower and upper limits of substances typically combusted in flares (Docket No. A–97–48, Item No. II–I–2).

The third phenomenon explaining the difference in combustion between hydrogen and organics is the relative difference in diffusivity between hydrogen and organics in air. Diffusivity refers to how easily molecules of one substance mix with molecules of another. Further, the quicker the fuel and air in a flare mix, the quicker the combustion reaction occurs. The measure of how quickly a substance mixes with another substances is expressed in terms of the diffusivity coefficient. The larger the diffusivity coefficient, the quicker the mixing. The diffusivity coefficient for the mixture of hydrogen and air is an order of magnitude higher than those for the mixture of air and volatile HAP with readily available diffusivity coefficients. Therefore, hydrogen is more diffuse in air compared to organics and more quickly enters the flammability range than organics.

B. Use of DuPont Test Results as the Basis for Hydrogen-Fueled Flare Specifications

These tests were conducted by DuPont primarily for their flaring conditions. However, after reviewing the test plan, observing the testing, and thoroughly reviewing the test report supplied by DuPont, the EPA concluded that the test results were applicable to all nonassisted flares with a hydrogen content of 8.0 percent (by volume) or greater, and a diameter of 3 inches or greater. The EPA believes that the test results are universally applicable since all the effective data points demonstrated a destruction efficiency greater than 98 percent, with the majority achieving greater than 99 percent destruction. Therefore, if the test flare can achieve these destruction efficiencies, then the EPA expects industrial flares meeting the flare specifications in these amendments to achieve a destruction efficiency of 98 percent or greater.

In selecting the conditions under which the pilot flare testing was to be conducted and interpreting the results of the testing, a "conservative" decision was made for each choice, that is the condition that would most likely assure that a full-scale flare would achieve at least as high and possibly higher destruction efficiency was chosen. This approach applied to the selection of flare tip design, flare tip diameter, pilot burner heat input, and characteristics of the surrogate for HAP for destruction testing. It also applied to the evaluation of stability testing and destruction efficiency results, as well as the selection of operating limits applying to hydrogen concentration and tip discharge velocity.

1. The Selection of the Flare Type

A nonassisted, plain-tip flare was used in the testing program because all of DuPont's flares are nonassisted. A nonassisted flare is a flare tip without any auxiliary provision for enhancing the mixing of air into its flame. The plain-tip means no tabs or other devices to redistribute flow were added to the rim of the flare. Because the presence of tabs improves the stability of the flare by channeling the flare's flow and improving mixing of fuel and air, it was concluded that the lack of tabs (i.e., plain tip) would result in the least stable test conditions.

2. The Comparison of the Selected Flare with the Existing Flare Specifications

A 3-inch flare was selected for the emission test since this was the same size flare used for the testing to establish the basis for the existing flare specifications in 40 CFR 60.18 and 40 CFR 63.11. Stability tests were conducted using propane to determine if the flare was operating properly and could meet the existing flare specifications. Test results demonstrated that this flare was stable when it was expected to be stable and not stable when it was not expected to be (i.e., as indicated by the existing flare specifications).